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CKM 2016

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Mini-review on R(D) and R(D*) at B-Factories

Marcello Rotondo
Laboratori Nazionali di Frascati

On behalf of BaBar and Belle

Semitauonic B decays at B-Factories

- First observation of the $B^0 \to D^{*2} \tau\nu$ PRL 99 (2007) 191807
  - Belle, Inclusive tagging technique
- Observation of the $B \to D^{*-}\tau\nu$ and evidence for $B \to D\tau\nu$ PRL100(2008)021801
  - BaBar, Hadronic tag
- Observation of the $B^+ \to D^{*0-}\tau\nu$ and evidence for $B^+ \to D^0\tau\nu$ PRD82(2010)072005
  - Belle, Inclusive tag

- Evidence for an excess of $B \to D(*)^-\tau\nu$ decays PRL109 (2012)101802
  - Babar, Hadronic tag, full BaBar statistics + improved tag first direct measurement of R(D) and R(D*)
- Measurement of R(D) and R(D*), PRD92(2015)072014
  - Belle, Hadronic tag
- Measurement of R(D) and R(D*), PRD94(2016) 072007
  - Belle, Semileptonic tag
- Measurement of R(D*) and t polarization, arxiv 1698.06391
  - Belle, Hadronic tag

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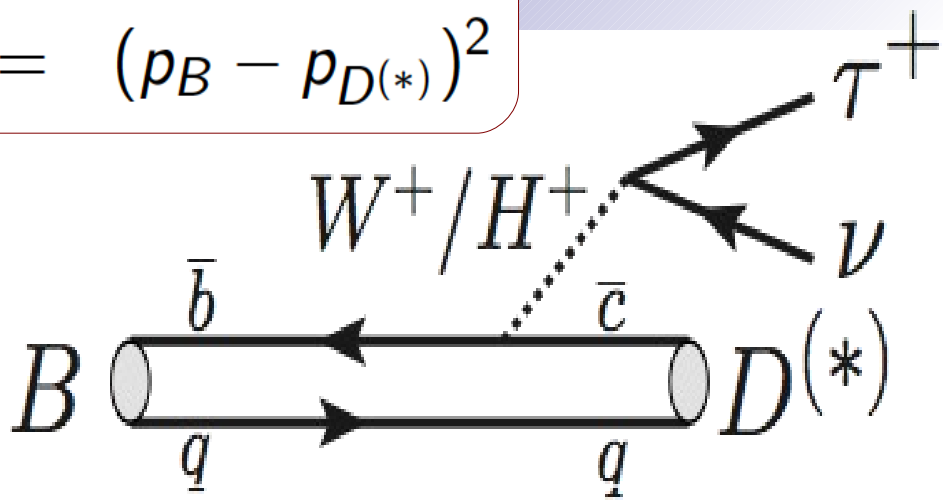
Talk by K. Adamczyk

$B \to D^{(*)}\tau\nu$

$$q^2 = (p_\ell + p_\nu)^2 = (p_B - p_{D^{(*)}})^2$$

- It is not a rare decay: BF~1-2%
- 3-body decay: many observables sensitive to NP can be exploited



Signal

$$\mathcal{R}(D^{(*)}) \equiv \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

Normalization
(largest background)

Theoretically Clean

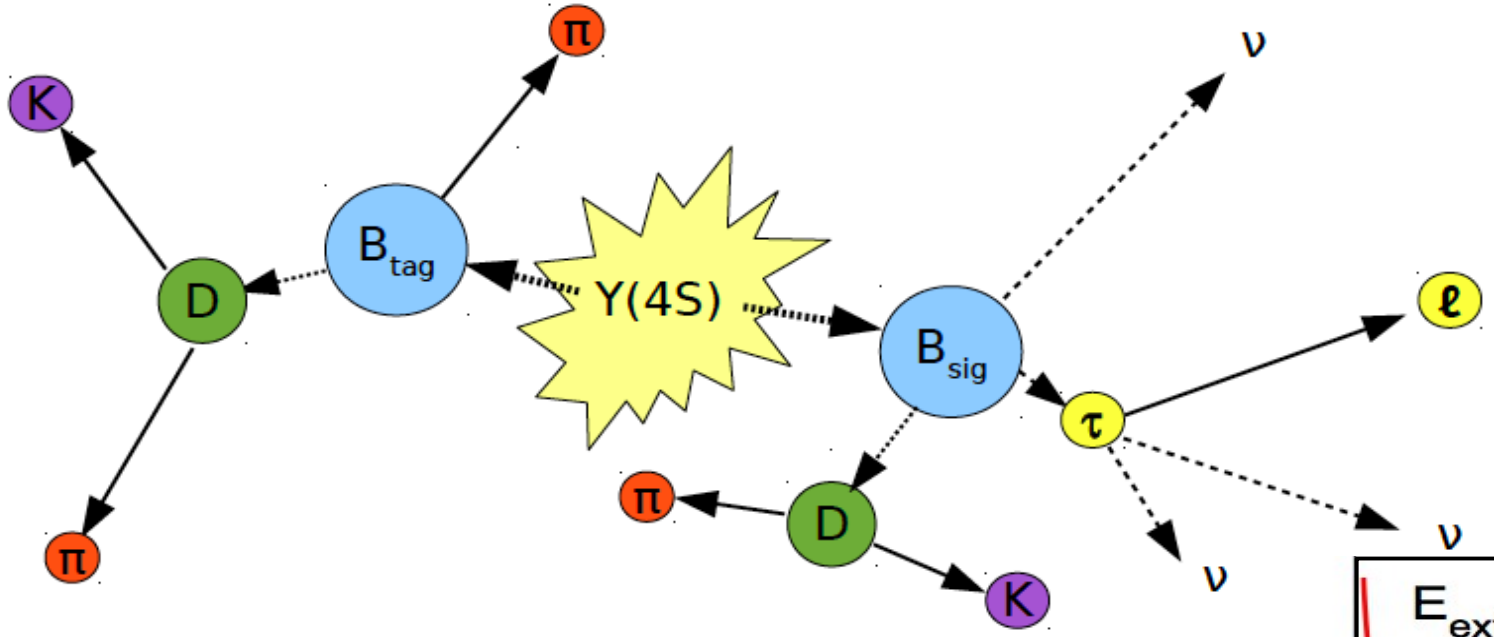
Cancellation of $|V_{cb}|$ and Form Factor uncertainties (partially: the helicity-suppressed amplitude estimated from HQET)

- Experimentally clean with leptonic tau decays
  - $\mathcal{B}(\tau \to \mu\nu\bar{\nu}), \mathcal{B}(\tau \to e\nu\bar{\nu}) \approx 17\%$
- Identical visible final state and direct access to *R*(D) and *R*(D*) ratios

Tagging at BFactories

Weak signal signature

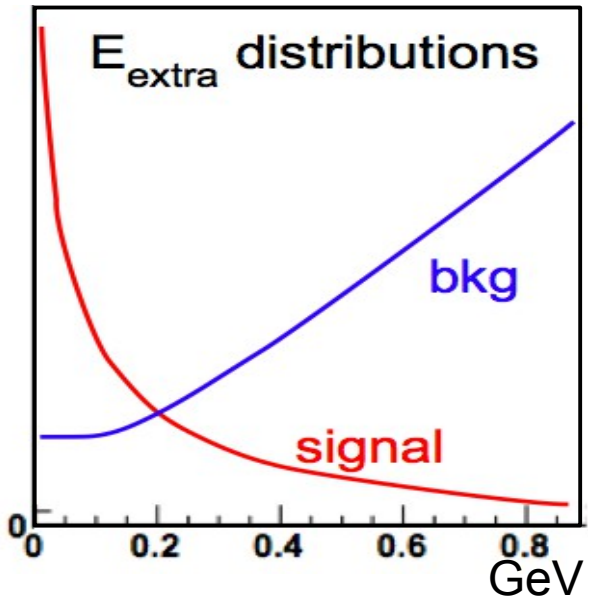
- Many neutrinos in the final state
- Lack of kinematic constraints



- Hadronic B tagging, determines charge and momentum of signal B, tag efficiency ~0.2-0.4%
- No additional charged tracks besides the signal and the tag side and little activity in the Calorimeter

Residual energy in the Calorimeter

$$E_{\mathrm{Extra}} = \sum_{\mathrm{unused}\ \gamma} E_{\gamma}$$



Fit $B \to D^{(*)}\tau\nu$: Yields Extraction

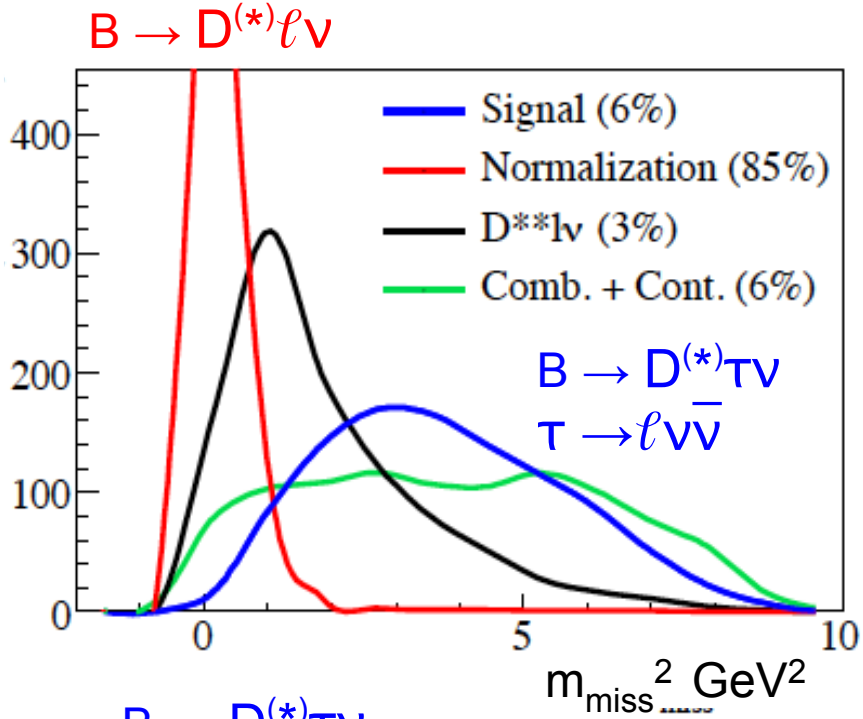
PRL109,101802(2012)
PRD 88,072012(2013)

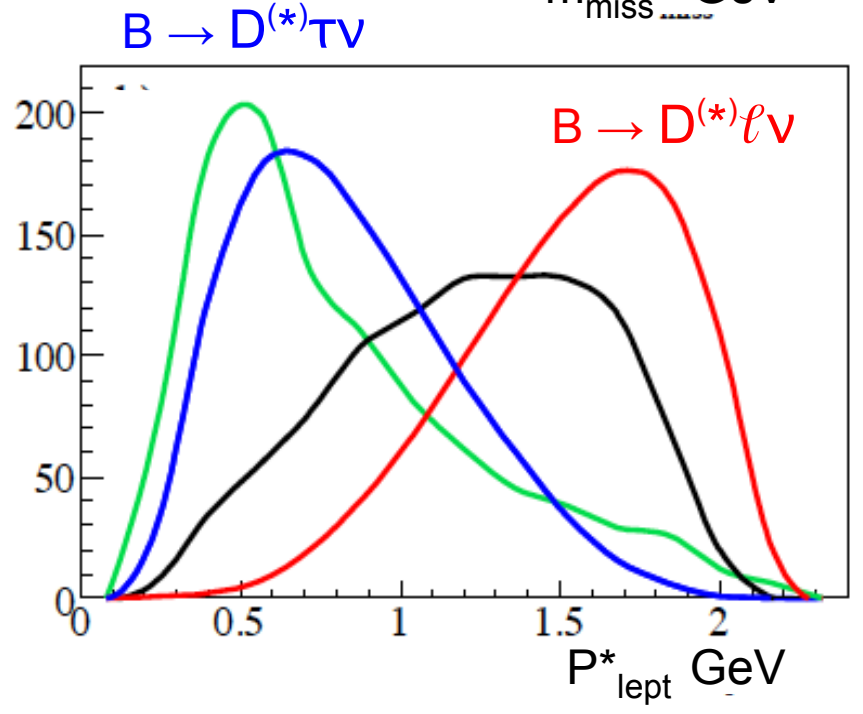
- Simultaneous un-binned M.L. Fit
  - 4 signal samples $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, D^{*+}
  - 2 dimensional distributions:

$$m^2_{miss} = (p_{e^+e^-} - p_{tag} - p_{D^{(*)}} - p_\ell)^2$$

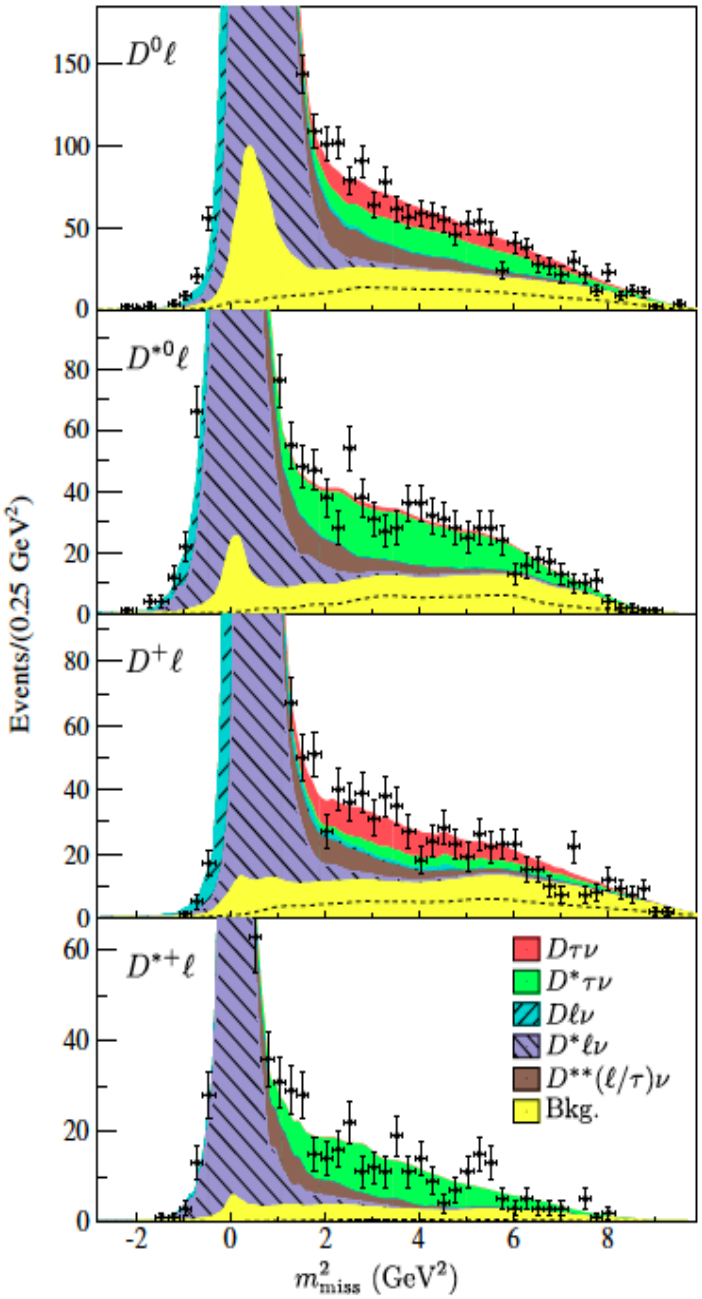
p^*_ℓ in the B_{sig} rest-frame

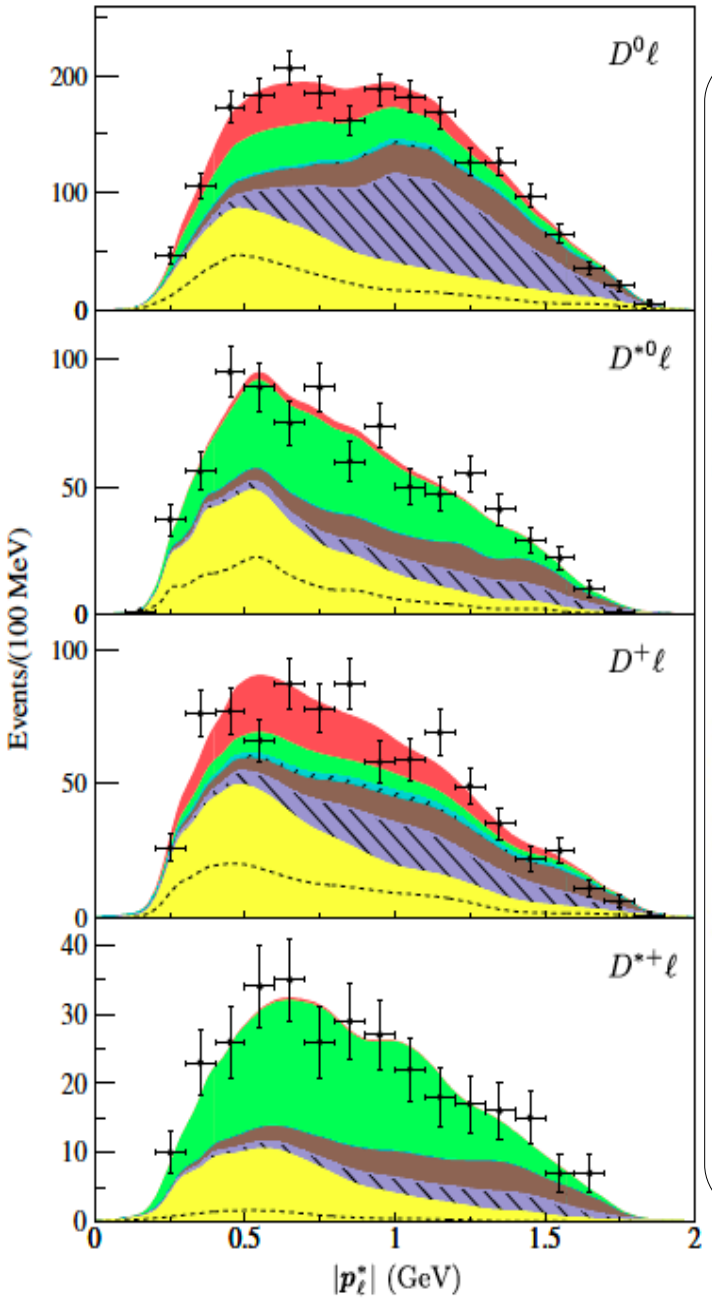
- Signal extracted together with a control sample of $B \to D^{**}$ selected by the presence of a π^0



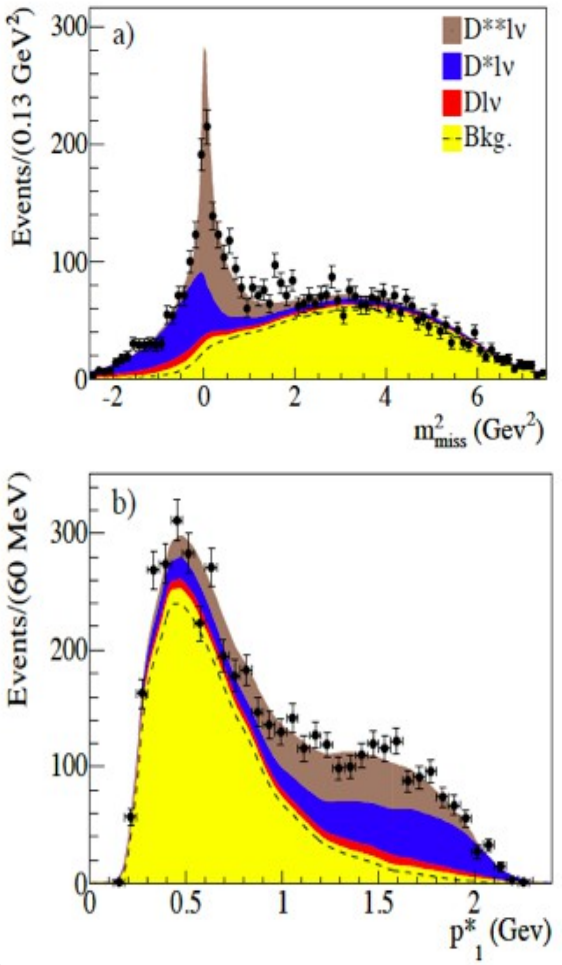


Results for B→D(*)τν





Summing
$D\pi^0\ell$, $D^*\pi^0\ell$



Results & Systematics

$$\mathcal{R}(D) = 0.440 \pm 0.058 \pm 0.042$$
$$\mathcal{R}(D^*) = 0.332 \pm 0.024 \pm 0.018$$

3.4σ from SM

- Dominant systematics
  - MC statistics
  - Factor $f_{D^{**}}$ that links the D** yields in the D(*)$\ell\pi^0$ and D(*)ℓ samples
  - Uncertainty due to D(*)ππ obtained by adding a further component to the fit
  - Corrections to fixed $B\bar{B}$ bkg and continuum

Source of uncertainty	$\mathcal{R}(D)$	$\mathcal{R}(D^*)$
Additive uncertainties		
PDFs	%	%
MC statistics	4.4	2.0
$\bar{B} \to D^{(*)}(\tau^-/\ell^-)\bar{\nu}$ FFs	0.2	0.2
$D^{**} \to D^{(*)}(\pi^0/\pi^\pm)$	0.7	0.5
$\mathcal{B}(\bar{B} \to D^{**}\ell^-\bar{\nu}_\ell)$	0.8	0.3
$\mathcal{B}(\bar{B} \to D^{**}\tau^-\bar{\nu}_\tau)$	1.8	1.7
$D^{**} \to D^{(*)}\pi\pi$	2.1	2.6
Cross-feed constraints		
MC statistics	2.4	1.5
$f_{D^{**}}$	5.0	2.0
Feed-up/feed-down	1.3	0.4
Isospin constraints	1.2	0.3
Fixed backgrounds		
MC statistics	3.1	1.5
Efficiency corrections	3.9	2.3
Multiplicative uncertainties		
MC statistics	1.8	1.2
$\bar{B} \to D^{(*)}(\tau^-/\ell^-)\bar{\nu}$ FFs	1.6	0.4
Lepton PID	0.9	0.9
$\pi^0/\pi^\pm$ from $D^* \to D\pi$	0.1	0.1
Detection/Reconstruction	0.7	0.7
$\mathcal{B}(\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau)$	0.2	0.2
Total syst. uncertainty	9.6	5.6
Total stat. uncertainty	13.1	7.1
Total uncertainty	16.2	9.0

Signal reconstruction

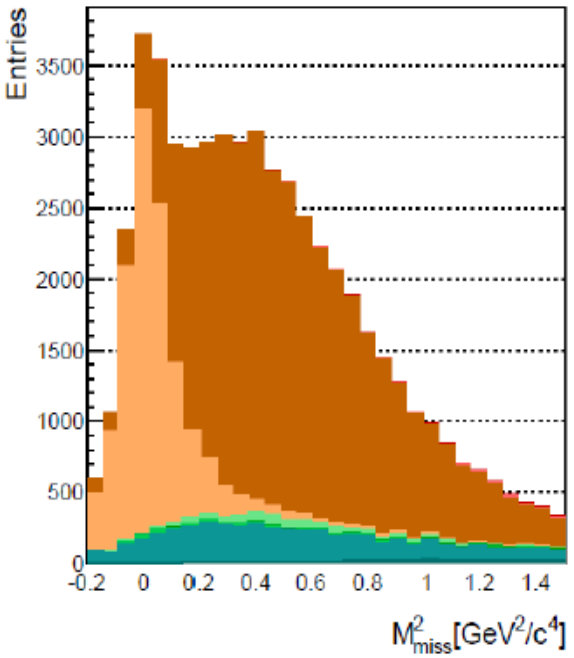
PRD92 (2015) 072014

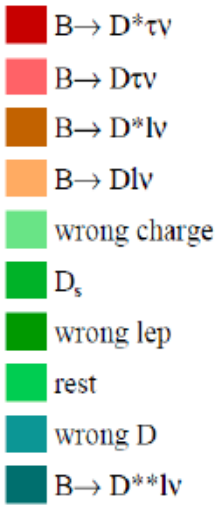
$M_{miss}^2 = (p_{e+e-} - p_{Btag} - p_{D(*)} - p_\ell)^2$

$q^2 = (- p_{Btag} - p_{D(*)})^2$

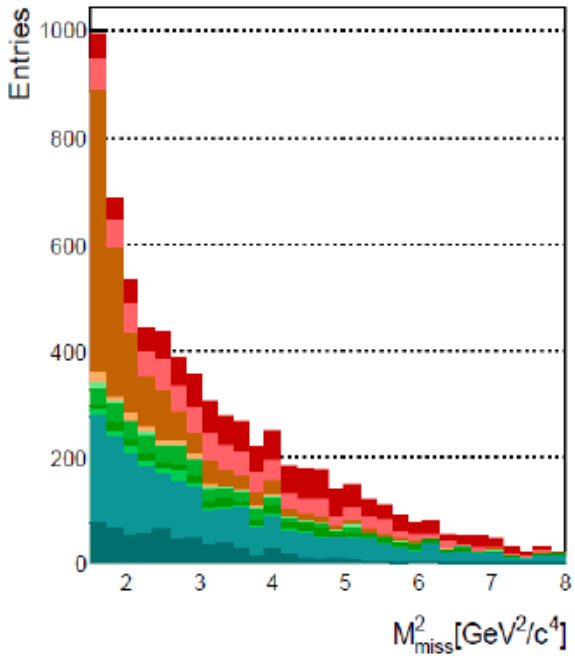
- Four signal samples $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, $D^{*+}\ell$
  - Uses the Hadronic Tagging
  - Zero charge of B_{tag} + B_{sig}
  - No further tracks and π^0 in barrel/forward/backward ECL region

$M_{miss}^2 < 1.5$ GeV^2





$M_{miss}^2 > 1.5$ GeV^2



Fit Strategy

M_{miss}^2 in low M_{miss}^2 sample constraints normalization and cross-feed.

Train a NN to distinguish tau signal and (mainly) D** background in high M_{miss}^2 sample.

Fit the NN distribution in high M_{miss}^2 to get the signal

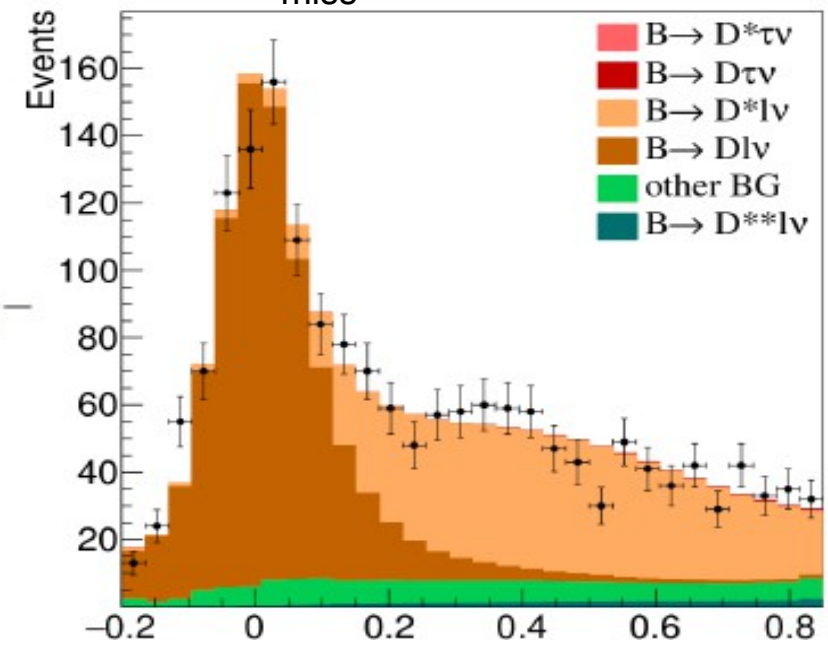
Fit results

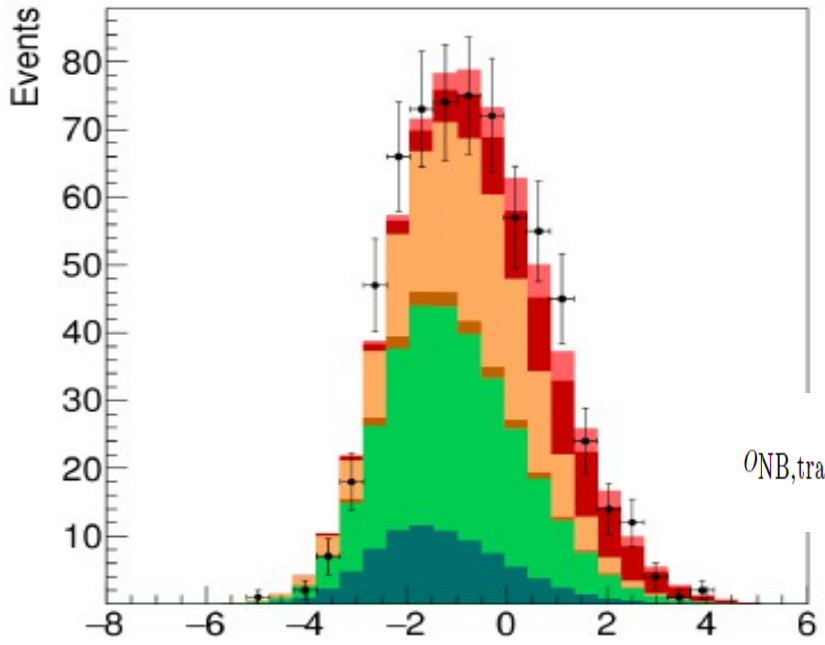
arXiv:1507.03233

$M_{miss}^2 < 0.85\ GeV^2$

$M_{miss}^2 > 0.85\ GeV^2$

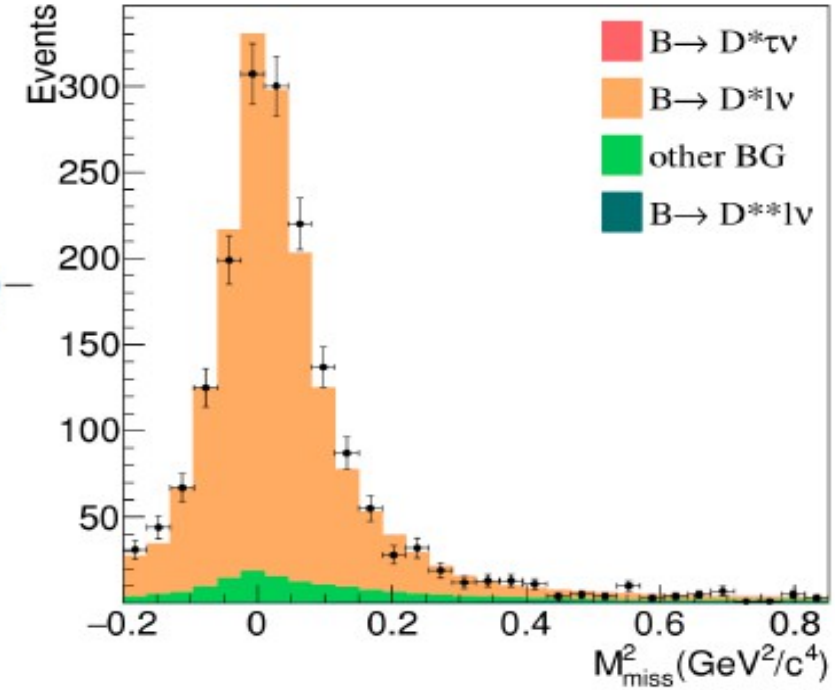
$D^+\ell^-$

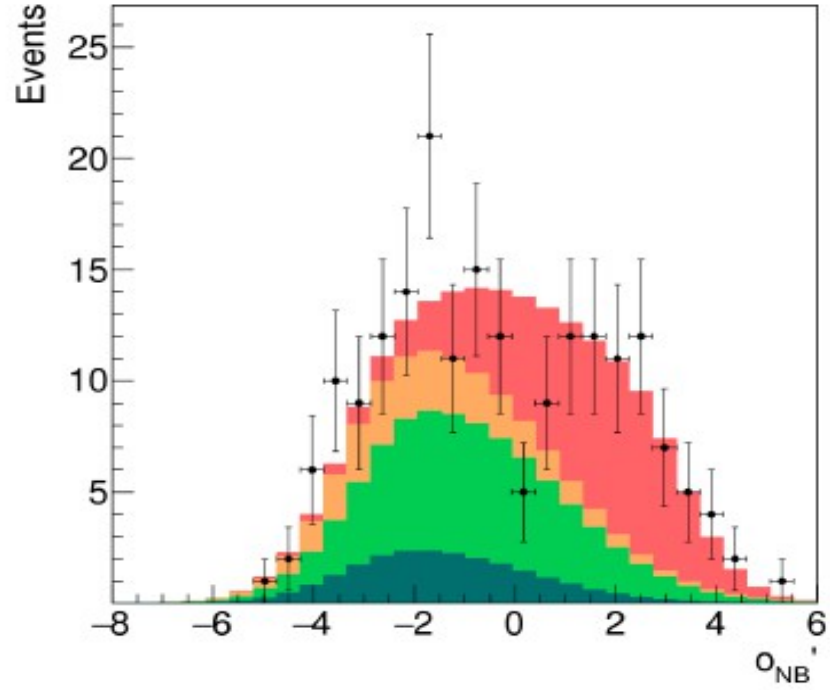




$$o_{NB,trafo} \equiv \log \frac{o_{NB} - o_{min}}{o_{max} - o_{NB}}$$

$D^{*+}\ell^-$





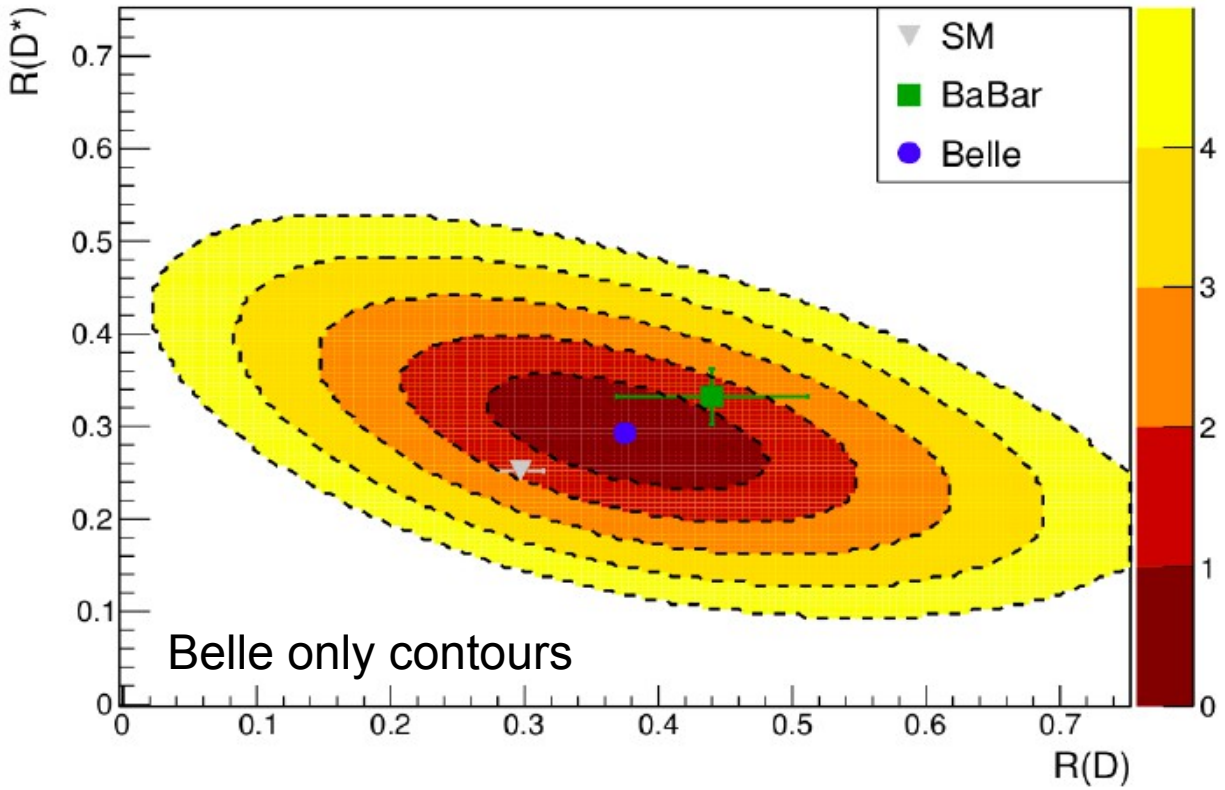
Results

PRD92 (2015) 072014

	R(D)	R(D*)
Belle	0.375 ± 0.064 ± 0.026	0.293 ± 0.038 ± 0.038
SM [*]	0.300 ± 0.008	0.252 ± 0.003
∞	1.4σ	1.8σ

No tension with either BaBar or SM

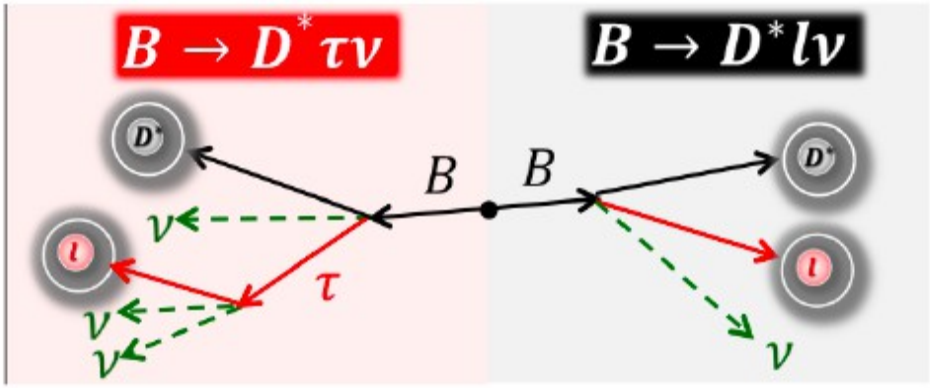
Comparison with SM calculation and BaBar measurement



	$R(D)$[%]	$R(D^*)$[%]	Correlation
$D^{(*(*))}\ell\nu$ shapes	4.2	1.5	0.04
D^{**} composition	1.3	3.0	−0.63
Fake D yield	0.5	0.3	0.13
Fake ℓ yield	0.5	0.6	−0.66
D_s yield	0.1	0.1	−0.85
Rest yield	0.1	0.0	−0.70
Efficiency ratio f^{D^+}	2.5	0.7	−0.98
Efficiency ratio f^{D^0}	1.8	0.4	0.86
Efficiency ratio $f^{D^{*+}}_{\rm eff}$	1.3	2.5	−0.99
Efficiency ratio $f^{D^{*0}}_{\rm eff}$	0.7	1.1	0.94
CF double ratio g^+	2.2	2.0	−1.00
CF double ratio g^0	1.7	1.0	−1.00
Efficiency ratio $f_{\rm wc}$	0.0	0.0	0.84
$M^2_{\rm miss}$ shape	0.6	1.0	0.00
$o'_{\rm NB}$ shape	3.2	0.8	0.00
Lepton PID efficiency	0.5	0.5	1.00
Total	7.1	5.2	−0.32

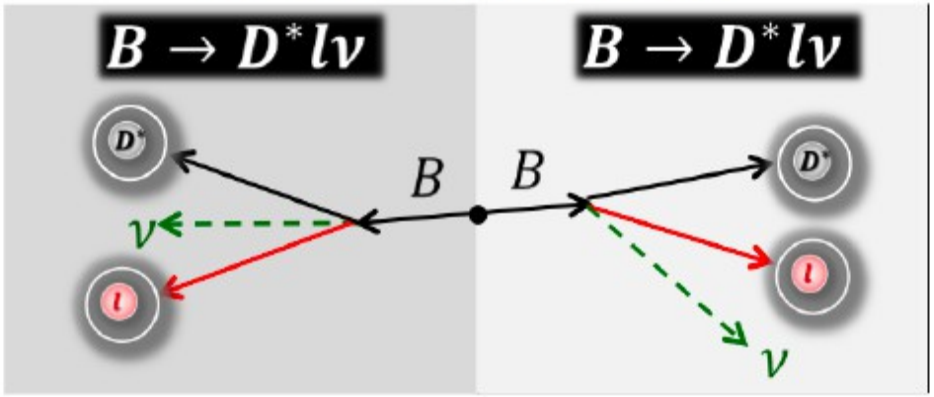
Belle result on R(D*) with Semileptonic Tag

Semitauonic signal-side decay and semileptonic tag-side.



Numerator in $\mathcal{R}(D^*)$

Normalization events are double semileptonic decays.



Denominator in $\mathcal{R}(D^*)$

More efficient than the hadronic tag
But less information about B_{tag} due to neutrino and it is not possiile to access the full kinematics

D^{*+} reconstruction
- both $D^0\pi^+$ and $D^+\pi^0$
- D^0 in 10 modes (~37%)
- D^+ 5 modes (~22%)

Tag semileptonic B-decay: D* with a lepton

$$\cos\theta_{B\text{-}D^*\ell} \equiv \frac{2E_{\rm beam}E_{D^*\ell} - m_B^2 - M_{D^*\ell}^2}{2|\vec{p}_B| \cdot |\vec{p}_{D^*\ell}|}$$

PRD94(2016) 072007

Signal yield extraction

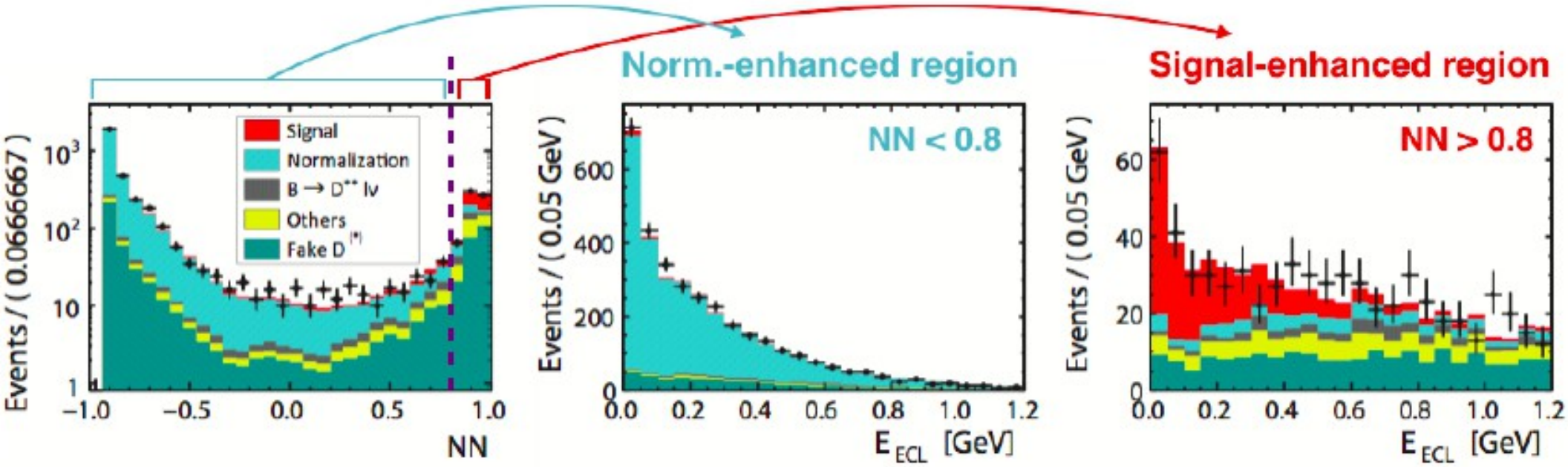
PRD94(2016) 072007

- Separate correctly reconstructed signal and normalization events using a NN (NeuroBayes) with M_{miss}^2 and total visible energy and $\cos\theta^{sig}_{BY}$

- Dominant backgrounds
  - Fake D*
  - $B \to D^{**}\ell\nu$
  - $B \to X_c D^*$ with $X_c \to$ semileptonically

Informations from E_{extra} (E_{ECL}) are used to fight these backgrounds

2D fit on NN and E_{ECL}



Results and systematics

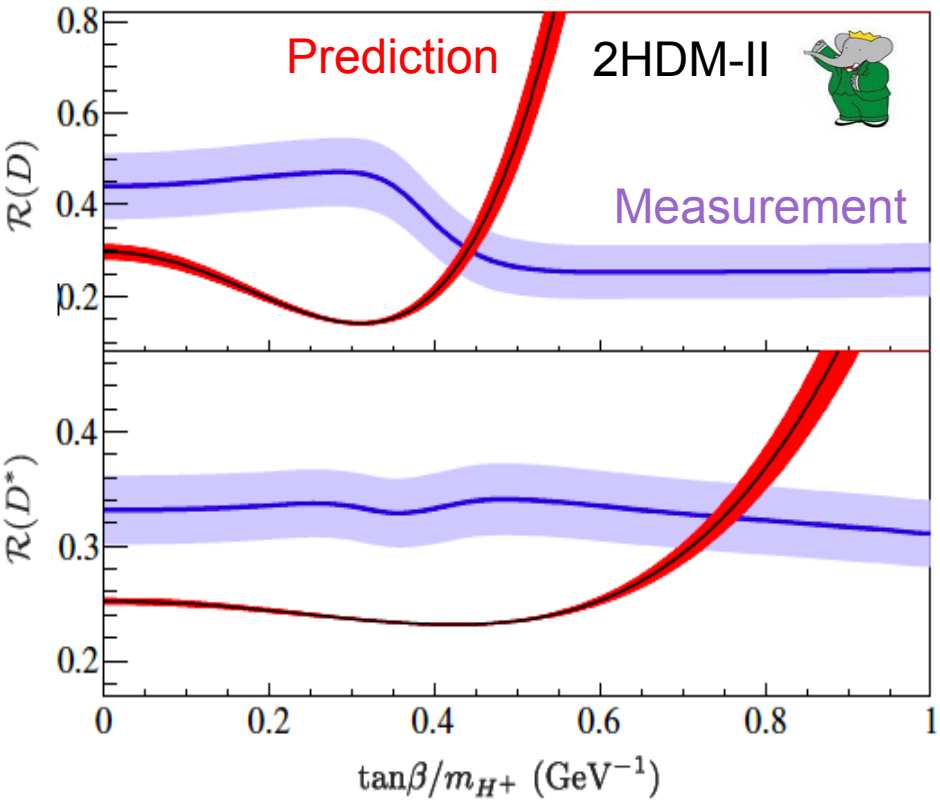
ArXiv:1603.06711

$$\mathcal{R}(D^*) = 0.302 \pm 0.030(\text{stat}) \pm 0.011(\text{syst})$$

Central value close to Belle hadronic Tag result
Precision improved over Belle and LHCb

	$\mathcal{R}(D^*)$ [%]		
Sources	$\ell^{\text{sig}} = e, \mu$	$\ell^{\text{sig}} = e$	$\ell^{\text{sig}} = \mu$
MC statistics for PDF shape	2.2%	2.5%	3.9%
PDF shape of the normalization	$^{+1.1}_{-0.0}$%	$^{+2.1}_{-0.0}$%	$^{+2.8}_{-0.0}$%
PDF shape of $B \to D^{**}\ell\nu_\ell$	$^{+1.0}_{-1.7}$%	$^{+0.7}_{-1.3}$%	$^{+2.2}_{-3.3}$%
PDF shape and yields of fake $D^{(*)}$	1.4%	1.6%	1.6%
PDF shape and yields of $B \to X_c D^*$	1.1%	1.2%	1.1%
Reconstruction efficiency ratio $\varepsilon_{\text{norm}}/\varepsilon_{\text{sig}}$	1.2%	1.5%	1.9%
Modeling of semileptonic decay	0.2%	0.2%	0.3%
$\mathcal{B}(\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau)$	0.2%	0.2%	0.2%
Total systematic uncertainties	$^{+3.4}_{-3.5}$%	$^{+4.1}_{-3.7}$%	$^{+5.9}_{-5.8}$%

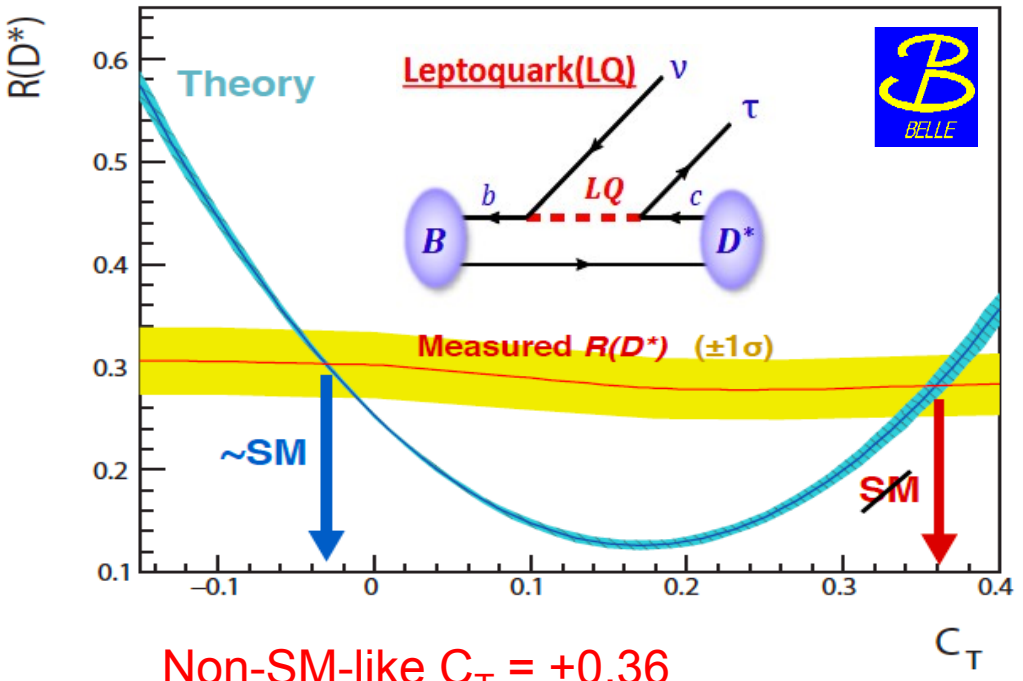
Constraints on New Physics



$$\mathcal{R}(D) \Longrightarrow \tan\beta/m_H = 0.44 \pm 0.02$$
$$\mathcal{R}(D^*) \Longrightarrow \tan\beta/m_H = 0.75 \pm 0.04$$

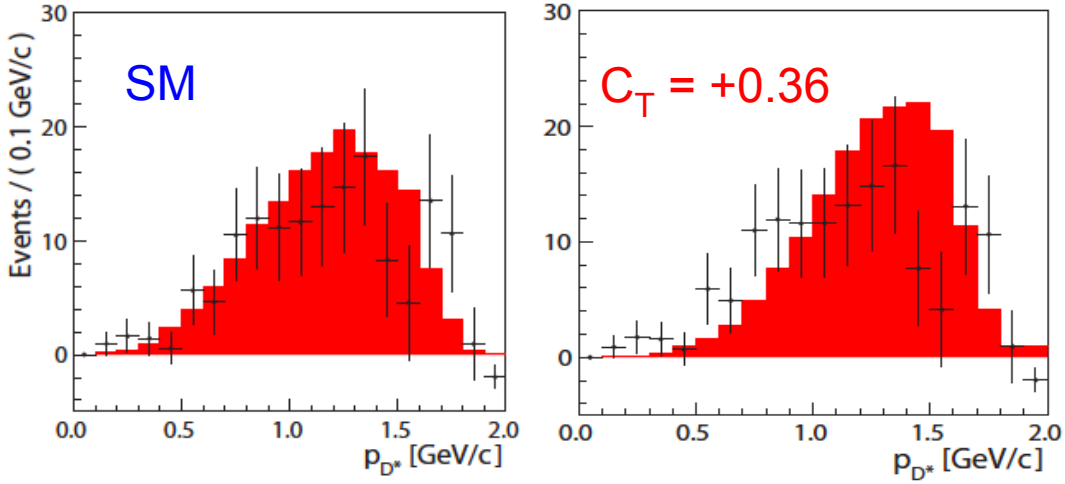
- The combination of R(D) and R(D*) excludes the 2HDM-II
- More general 2HDM-III can explain the data (more parameters)

LQ from PRD 87,034028(2013)



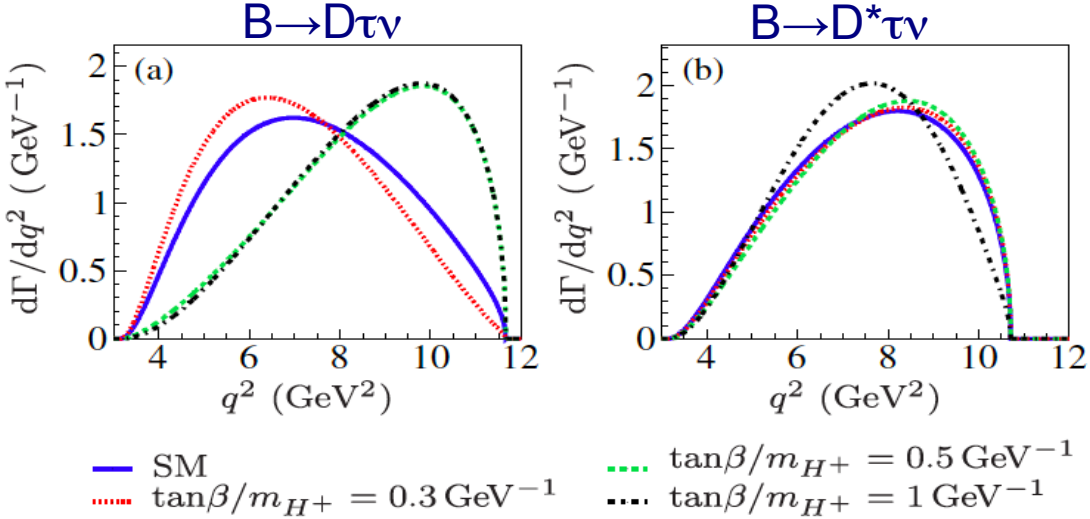
Non-SM-like C_T = +0.36

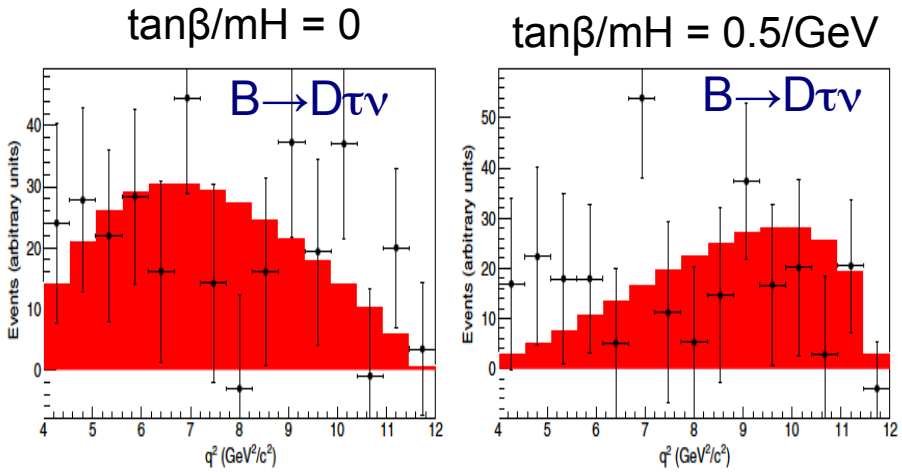
But disagreement in D* momentum

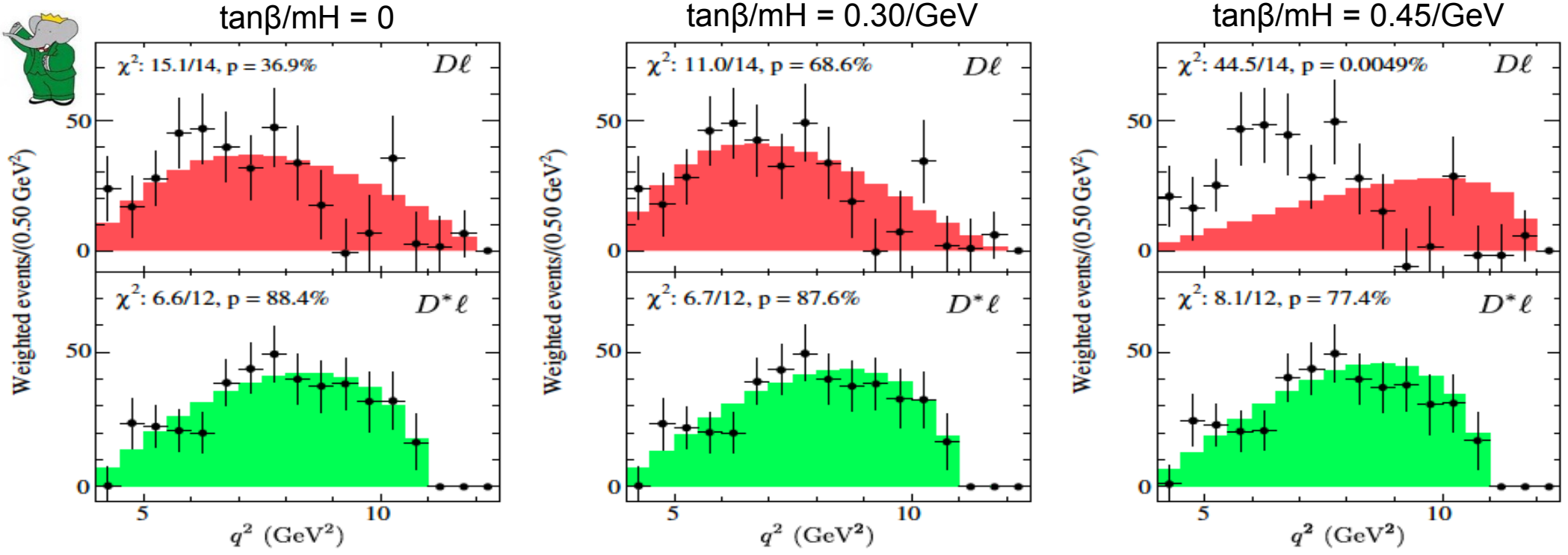


Beyond R(D) and R(D*): q^2

- The q^2 for $B \to D\tau\nu$ spectrum could be impacted by NP contributions







Prospects at Belle-II

Systematics from Belle Hadronic Tag analysis (example)

	$R(D)[\%]$	$R(D^*)[\%]$	Correlation
$D^{(*(*))}\ell\nu$ shapes	4.2	1.5	0.04
D^{**} composition	1.3	3.0	−0.63
Fake D yield	0.5	0.3	0.13
Fake ℓ yield	0.5	0.6	−0.66
D_s yield	0.1	0.1	−0.85
Rest yield	0.1	0.0	−0.70
Efficiency ratio f^{D^+}	2.5	0.7	−0.98
Efficiency ratio f^{D^0}	1.8	0.4	0.86
Efficiency ratio $f^{D^{*+}}_{\rm eff}$	1.3	2.5	−0.99
Efficiency ratio $f^{D^{*0}}_{\rm eff}$	0.7	1.1	0.94
CF double ratio g^+	2.2	2.0	−1.00
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Efficiency ratio $f_{\rm wc}$	0.0	0.0	0.84
$M^2_{\rm miss}$ shape	0.6	1.0	0.00
$o'_{\rm NB}$ shape	3.2	0.8	0.00
Lepton PID efficiency	0.5	0.5	1.00
Total	7.1	5.2	−0.32

- Currently measurements are dominated by statistical uncertainty
- Current total statistical uncer.: 12% on R(D) and 6% on R(D*) → **% level at Belle-II**
  - Systematics uncertainties related to the limited MC statistics: **fast MC**
  - Understand D** and double-charm background: **need more measurements**
  - Difference between data and MC are assigned as systematics and can be reduced: **statistics of control samples goes with luminosity**

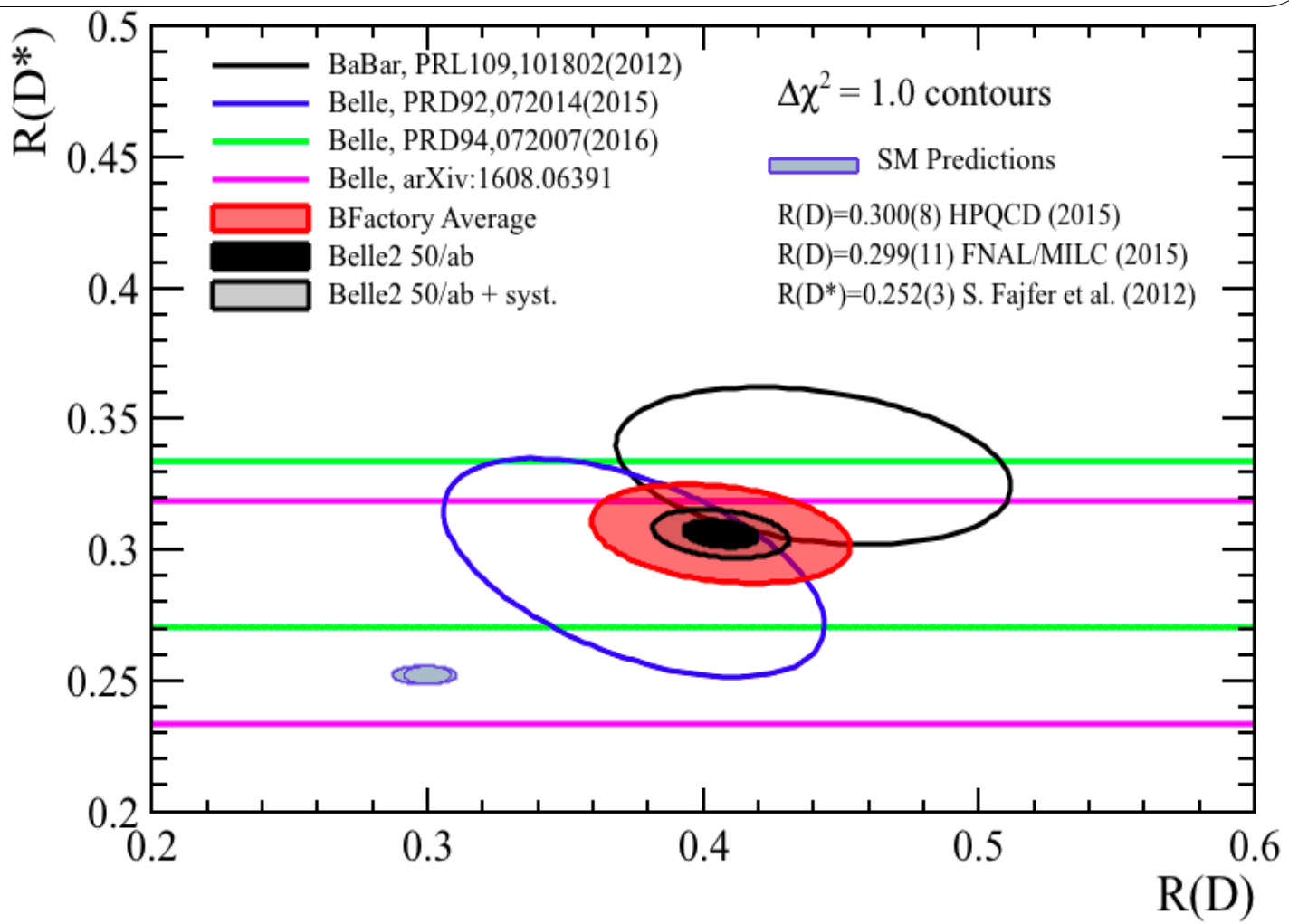
Belle-2 with 50ab^{-1}

Assuming 50ab^{-1} (no improvements on syst.)	50ab^{-1} and syst. reduced by factor 2
$\sigma(R_D) \sim 6\%$	$\sigma(R_D) \sim 3\%$
$\sigma(R_{D^*}) \sim 3\%$	$\sigma(R_{D^*}) \sim 1.7\%$

HFAG CKM2016 (including LHCb)

$\sigma(R_D) \sim 11.7\%$

$\sigma(R_{D^*}) \sim 6.1\%$



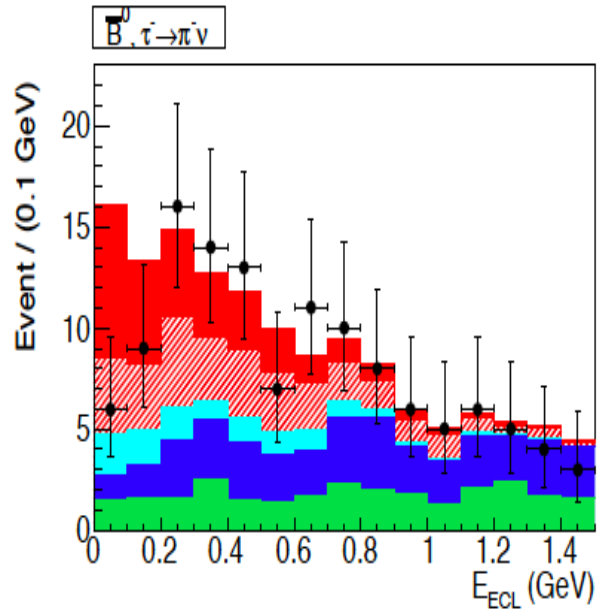
Future on semi-tauonic decays

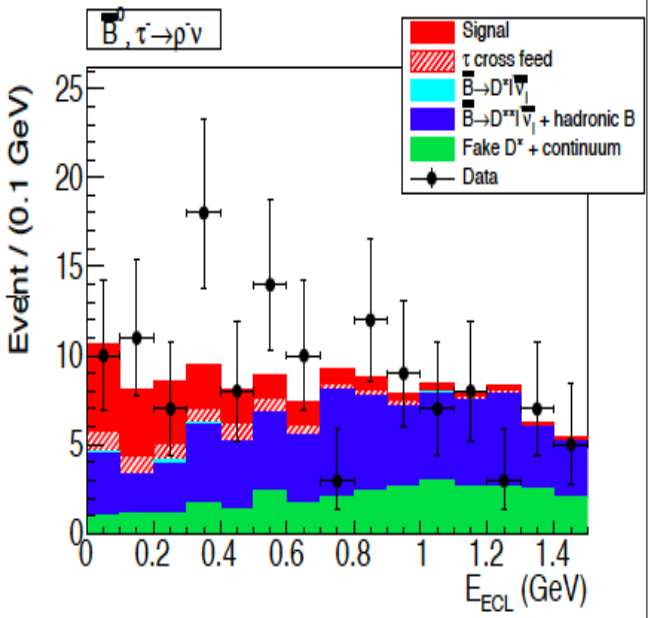
- Persistent discrepancy at 4σ level with the SM prediction on R(D) & R(D*)
  - Belle measurements are closer to the SM
- Bright future at Belle-II on semi-tauonic decays
  - Exploiting both leptonic and hadronic tau decays, with different tagging techniques
  - Uncertainties on R(D)-R(D*) can be reduced at the % level
  - Spectra are crucial and can be measured with high accuracy
    - Lepton polarization, q^2 spectrum, D* energy, FB asymmetry...
  - Decays that involve b→u transitions: recently Belle $Br(B \to \pi \tau \nu) < 2.5 \times 10^{-4}$
- Possibility to access other decays:
  - Semitauonics with $B \to D^{**} \tau \nu$
  - Running at Y(5S) it could be possible to access $B_s \to D_s(*) \tau \nu$

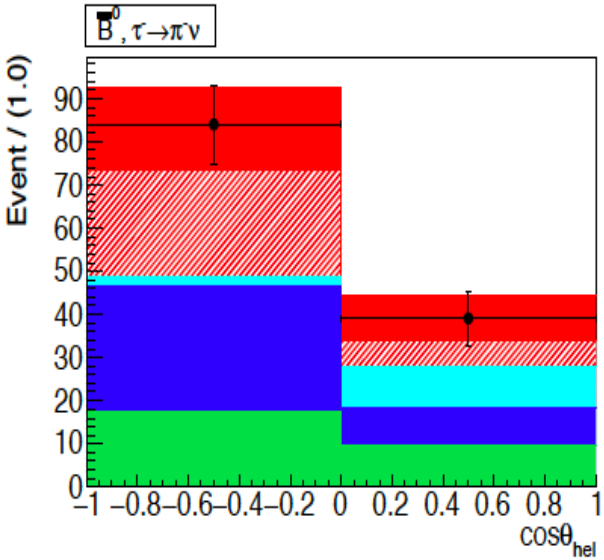
Backup

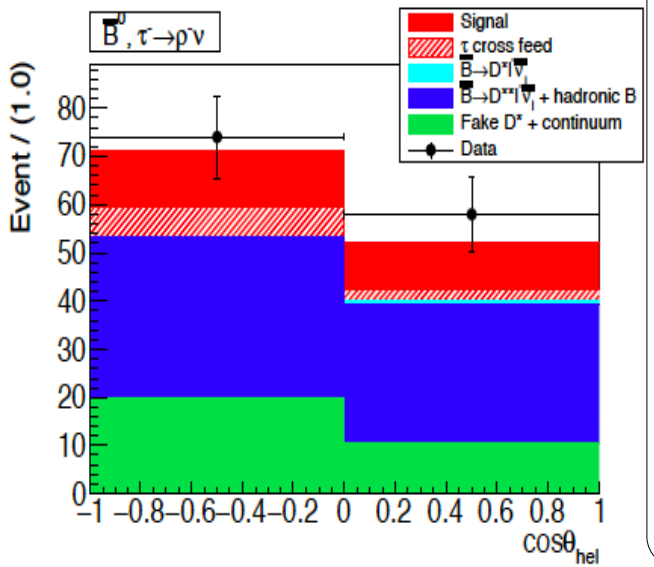
Result for R(D*) and tau polarization

Projections for the B^0









Dominant background

- Fake D* from sidebands
- Hadronic B decays with multipion-emissions
  - Control sample with additional tracks
  - Yield are floated in the fit

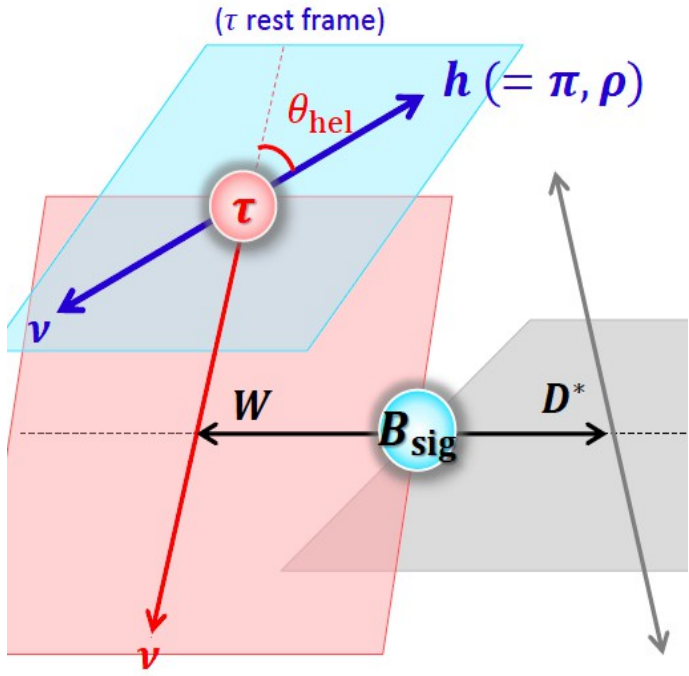
	Signal	
	(Signal)	(τ cross feed)
$(\bar{B}^0, \pi^- \nu_\tau)$	68.1 ± 8.5	82 ± 10
$(\bar{B}^0, \rho^- \nu_\tau)$	51.1 ± 6.4	17.0 ± 2.1
$(B^-, \pi^- \nu_\tau)$	29.7 ± 3.7	30.8 ± 3.8
$(B^-, \rho^- \nu_\tau)$	21.9 ± 2.7	8.3 ± 1.0

R(D*) with hadronic tag and τ polarization

- Helicity angle of tau is sensitive to polarization $\mathcal{P}_\tau$

$$\frac{1}{\Gamma}\frac{d\Gamma}{d\cos\theta_{hel}} = \frac{1}{2}(1 + \alpha \cdot \mathcal{P}_\tau \cos\theta_{hel})$$

  - 4-momentum of B_{sig} determined by the hadronic tag



- Two-body hadronic τ decays
  - $\tau \to h\nu, \quad h = \pi^-, \rho^- (\to \pi^-\pi^0)$
  - $\alpha = \begin{cases} 1 & \text{for } \tau \to \pi^-\nu \text{ (pseudo scalar meson)} \\ 0.45 & \text{for } \tau \to \rho^-\nu \text{ (vector meson)} \end{cases}$

- Simultaneous fit of eight distributions of E_{ECL}
  - B^0 and B^+
  - πν and ρν
  - Forward - backward $\cos\theta_{hel}$

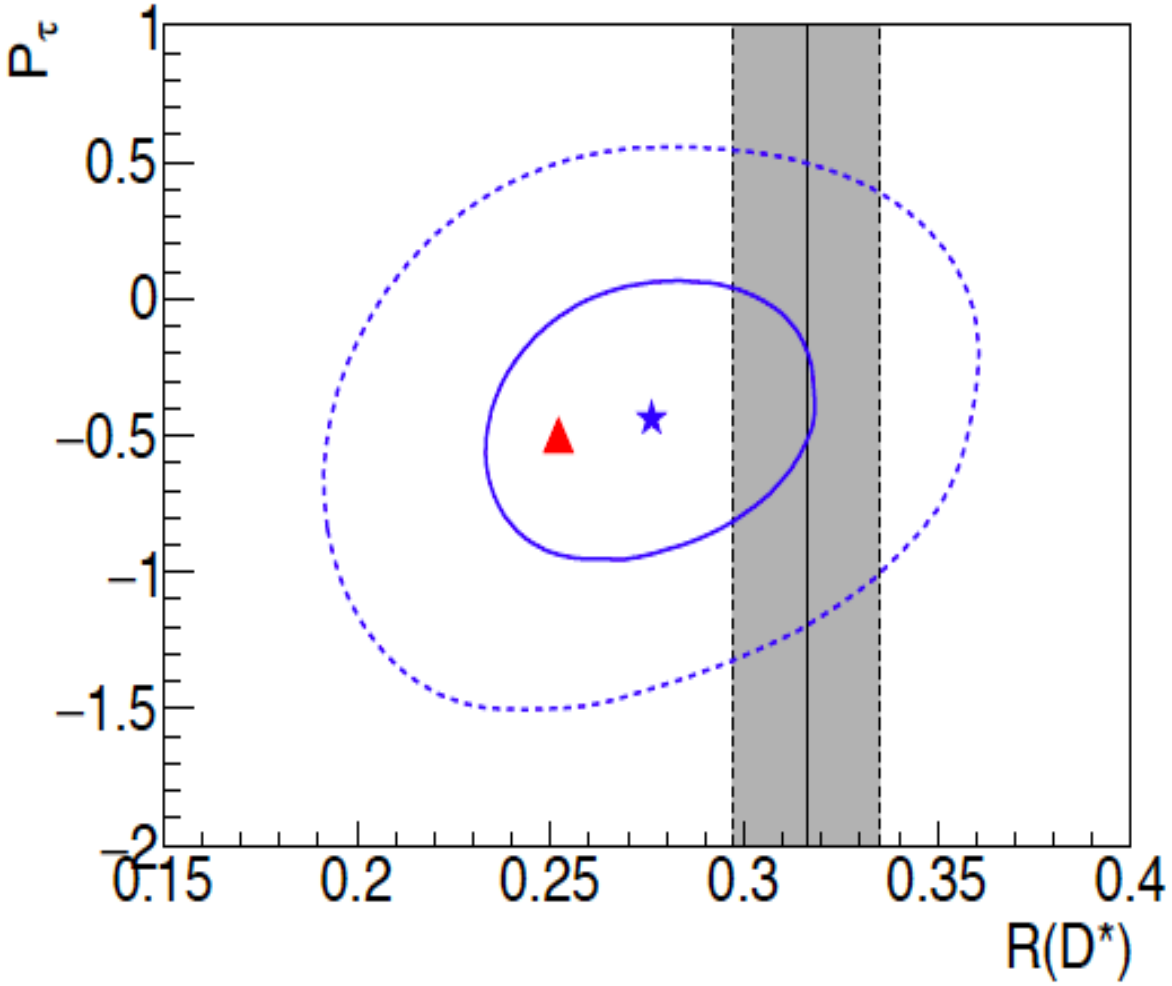
Results on R(D*) and $\mathcal{P}_\tau$

$$R(D^*) = 0.276 \pm 0.034(\text{stat.})^{+0.029}_{-0.026}(\text{syst.}),$$

$$P_\tau = -0.44 \pm 0.47(\text{stat.})^{+0.20}_{-0.17}(\text{syst.}).$$

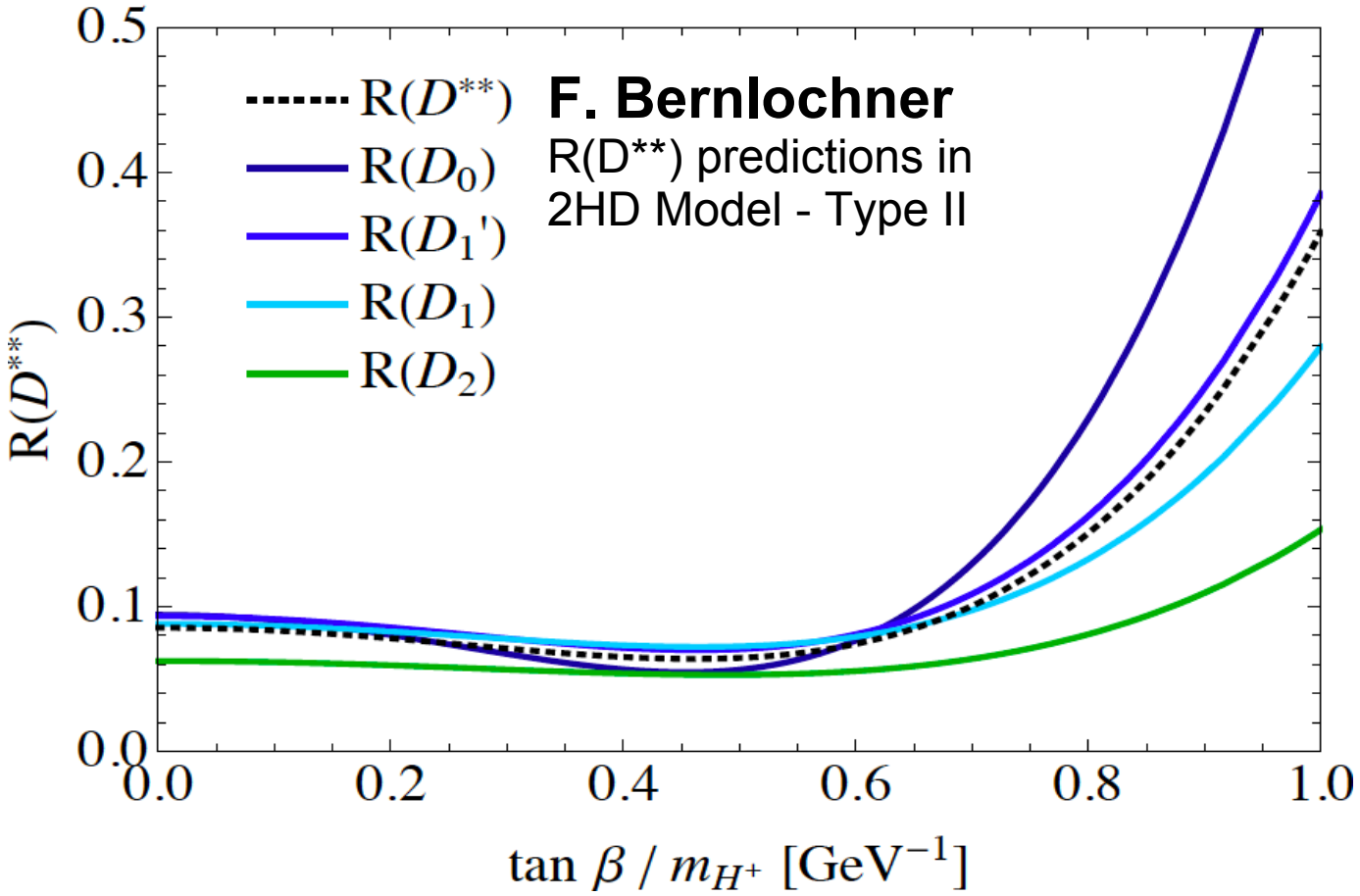
- R(D*) consistent with SM prediction and other measurements
- First measurement of $\mathcal{P}_\tau$: consistent with SM
  - -0.497 ± 0.014

Tanaka, Watanabe, PRD87,034028 (2013)



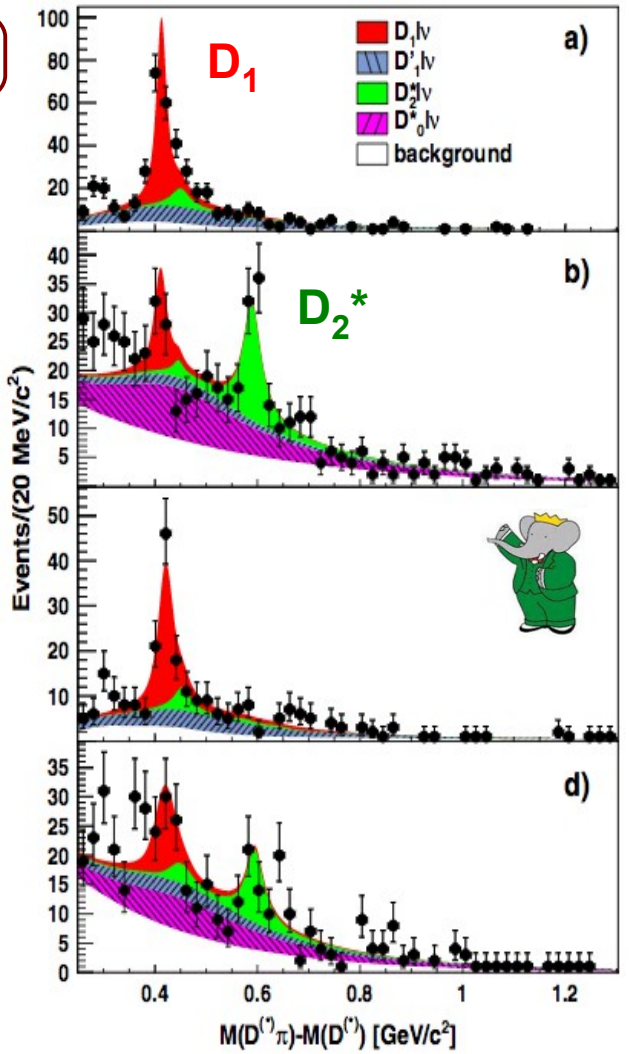
R(D**)

$s_l^{\pi l}$	Particles	J^P	m (GeV)	Γ (GeV)
$\frac{1}{2}^-$	$D,\ D^*$	$0^-,\ 1^-$	$1.87,\ 2.01$	
$\frac{1}{2}^+$	$D_0^*,\ D_1$	$0^+,\ 1^+$	$2.32,\ 2.43$	$0,27,\ 0.38$
$\frac{3}{2}^+$	$D_1,\ D_2^*$	$1^+,\ 2^+$	$2.42, 2.46$	$0.03,\ 0.05$



All possible non-SM operators can be explored

PRL101,261802(2008)

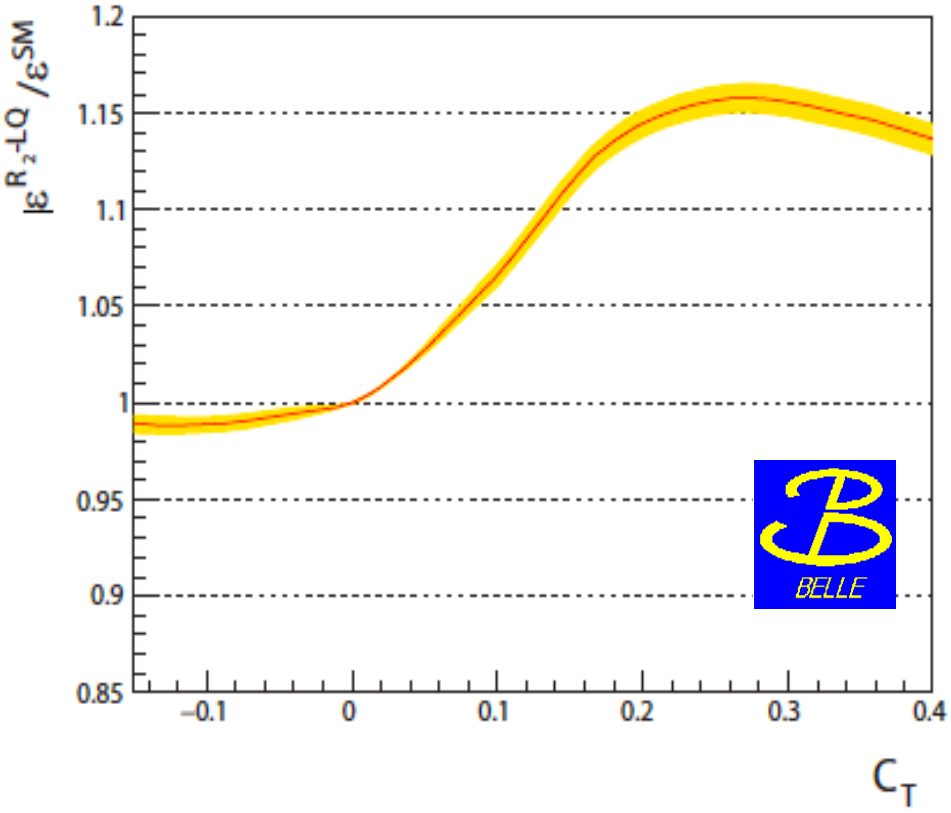


Can we explain the excess of events?

- For any assumed model and choice of parameters, we have to compute the efficiency and the impact on the kinematic shapes which affect the signal yields

- LeptoQuarks models (unified description of leptons and quarks)
  - B is sensitive to the tensor operator
  - R_2-type LQ are good candidate for compatibility test

PRD 87,034028(2013), PRD88,094012(2013)



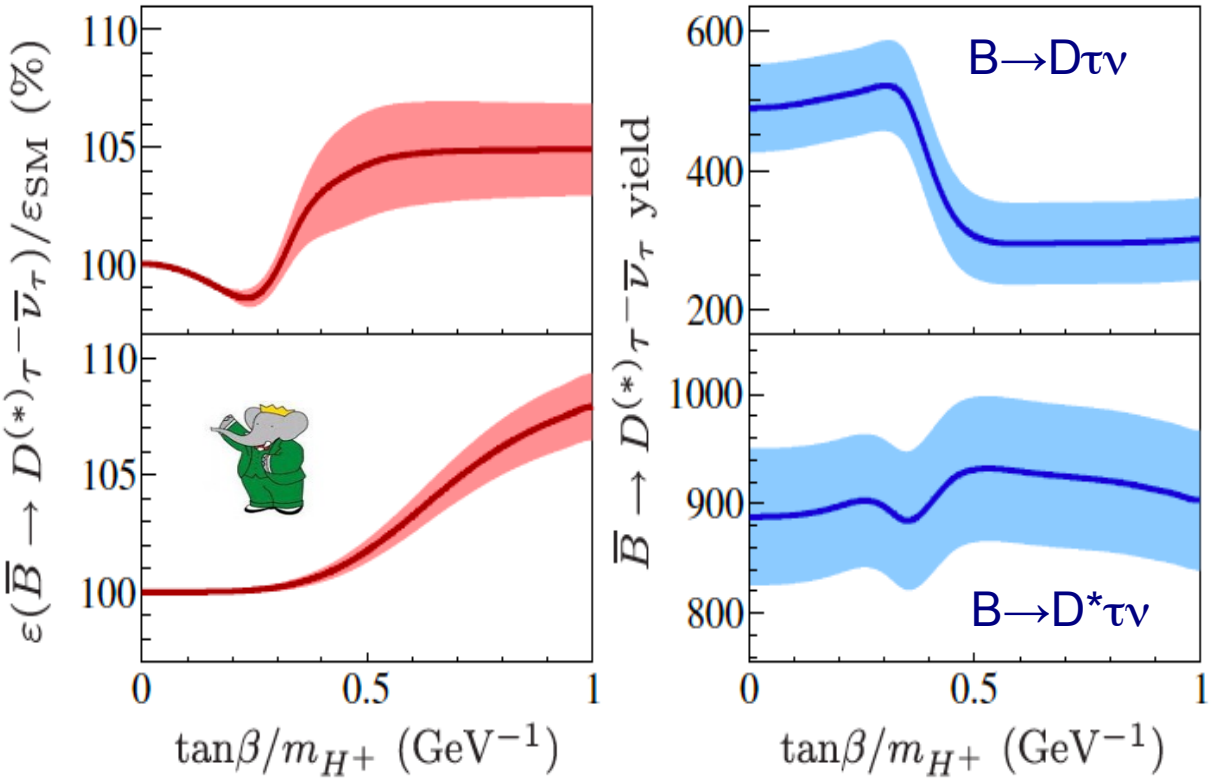
Can we explain the excess of events?

- For any assumed model and choice of parameters, we have to compute the efficiency and the impact on the kinematic shapes which affect the signal yields

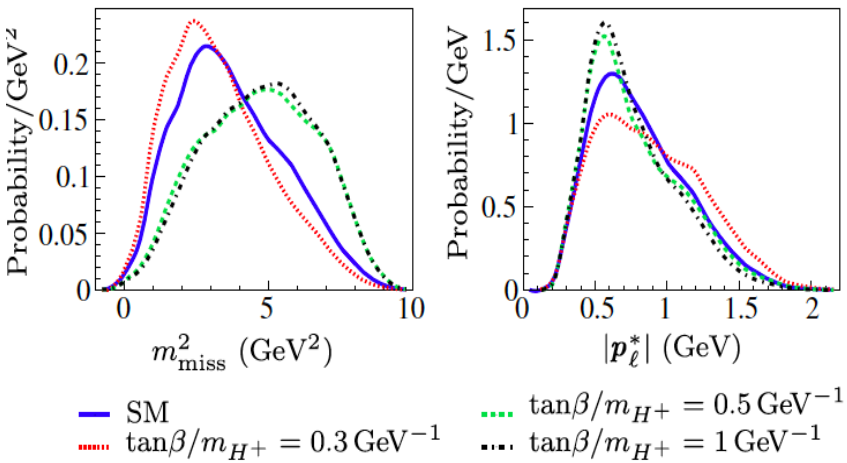
- For example Type II - 2HDM (now disfavored) a scalar charged Higgs affects only H_s

$$H_s^{\mathrm{2HDM}} \approx H_s^{\mathrm{SM}} \times \left(1 - \frac{\tan^2\beta}{m_{H+}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$

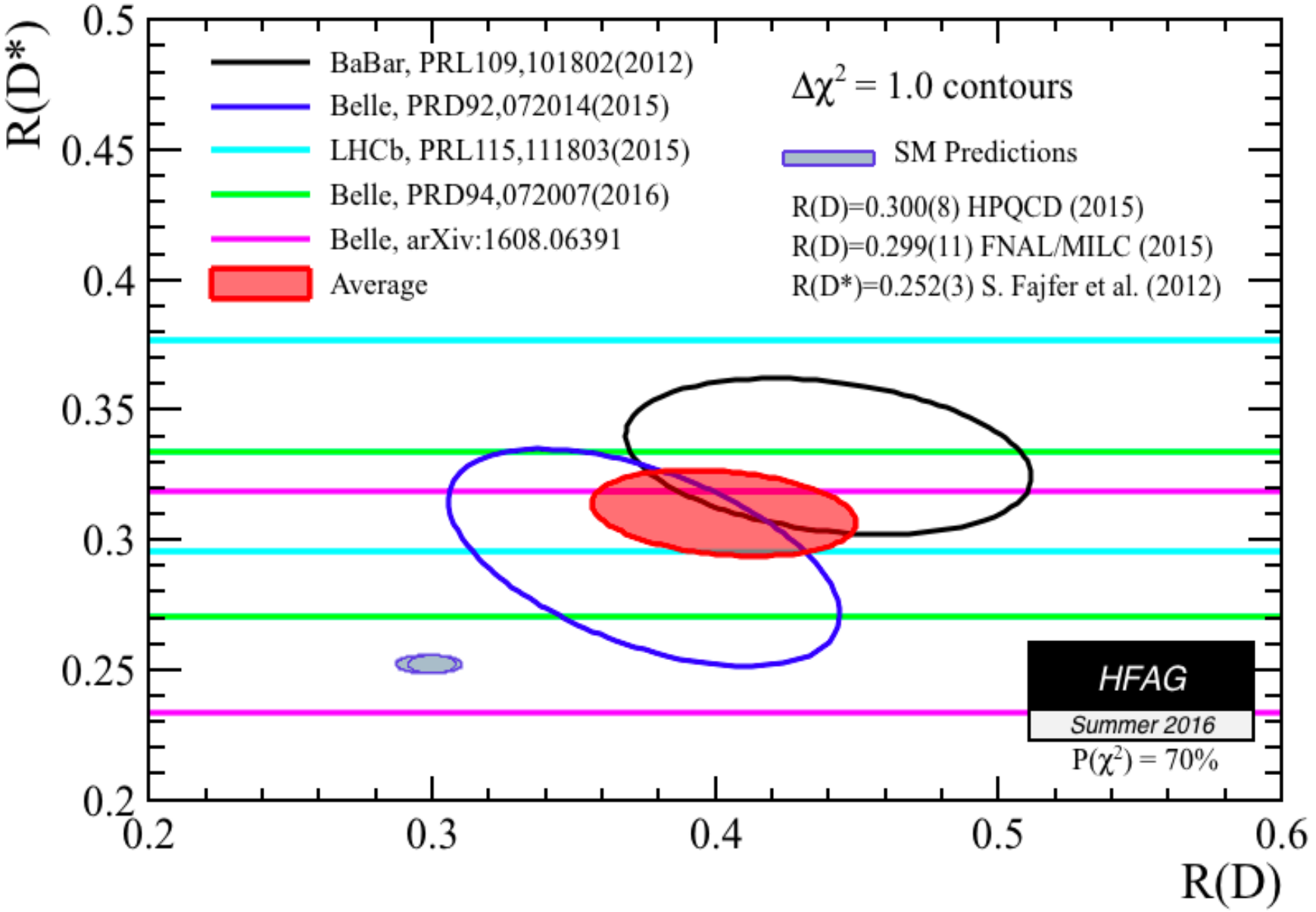
2 for B→Dτν & + for B→D*τν



Impact of NP on p* and m^2_{miss}

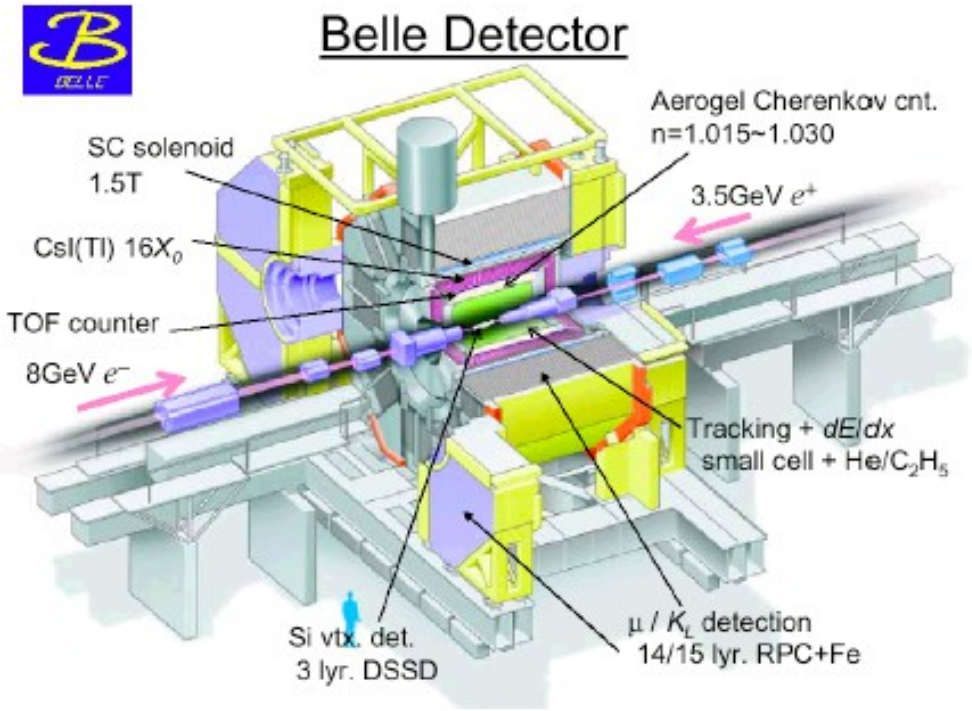


CKM16 HFAG average of R(D) and R(D*)

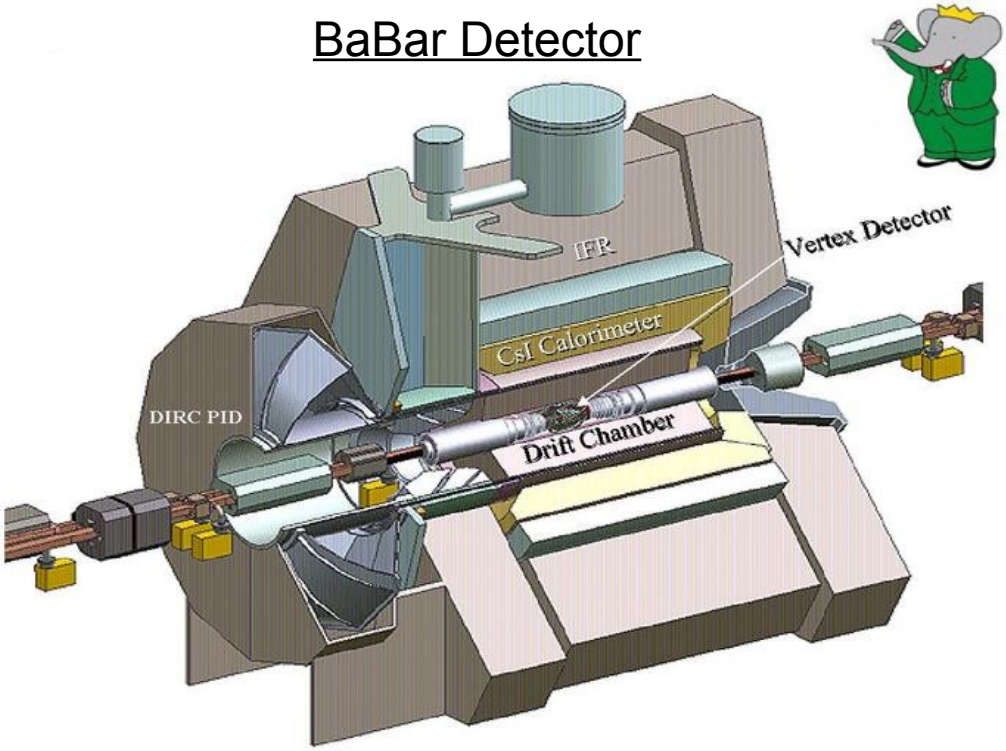


~4.0σ combined deviation from the SM including correlations

Experiments: B-Factories



@ KEK Japan: 1999-2009



@ SLAC: 1999-2008

B-Factories: hermetic detectors, low background, access (mainly) at $B^{0/+}$

About (771 + 467)x10^6
e^+e^- Y(4S) BB events in the Belle+BaBar data

Belle and KEK is being upgraded

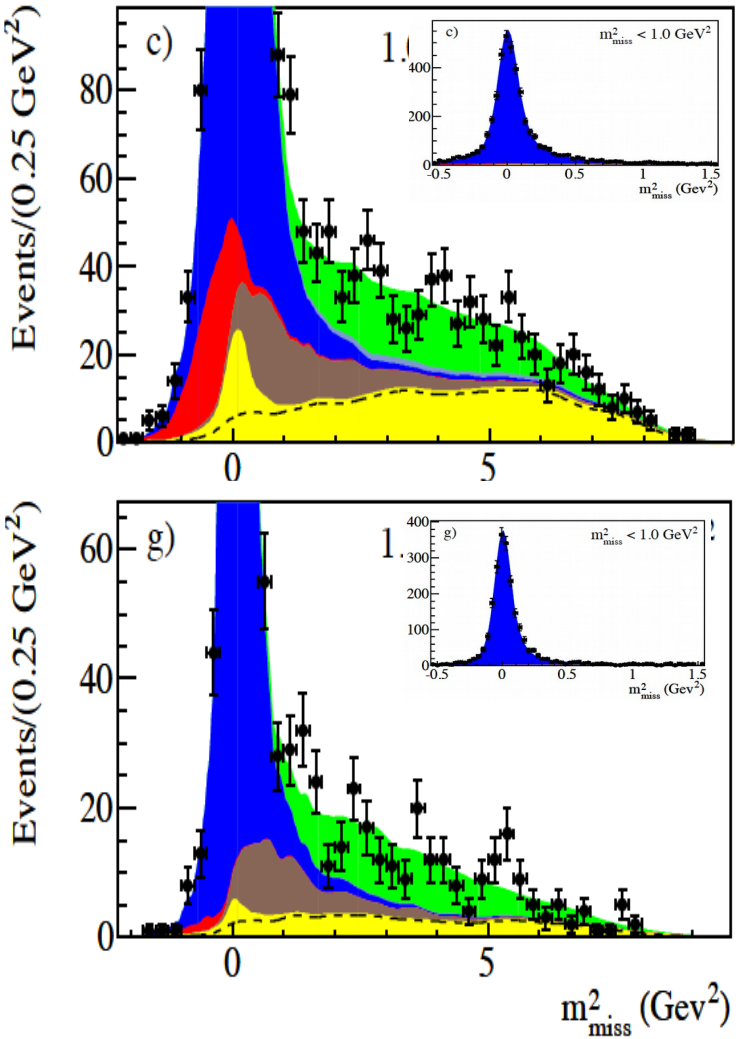
Belle-II aims to collect 50ab^{-1} by 2024

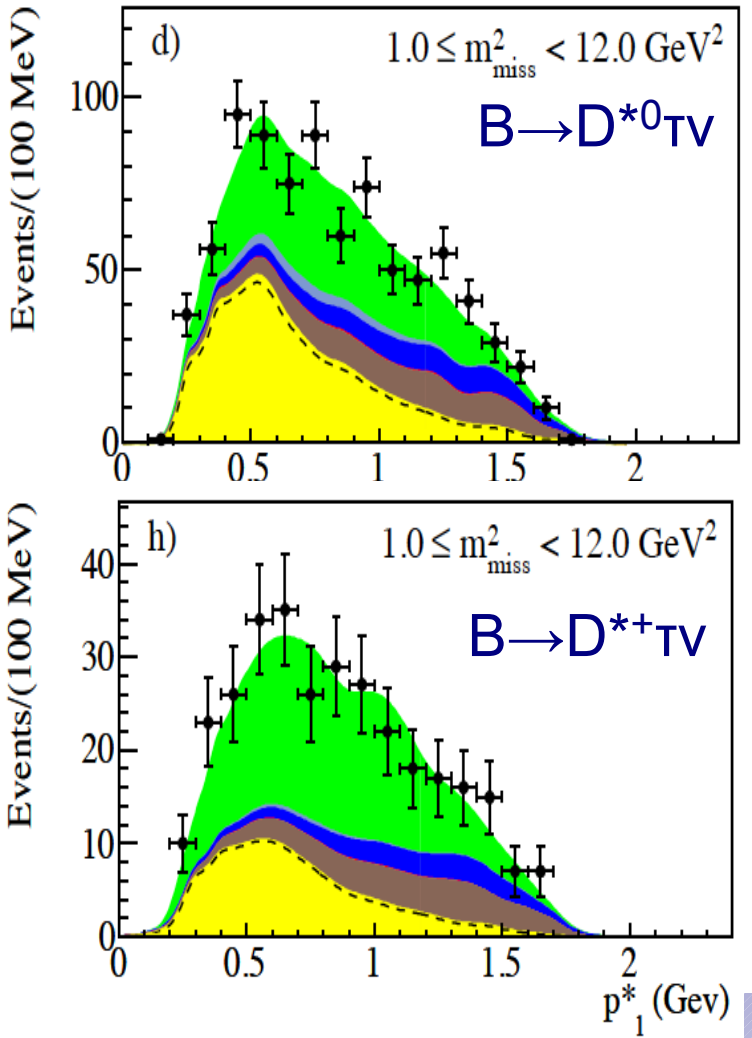
Results of Fit $B \to D^* \tau \nu$

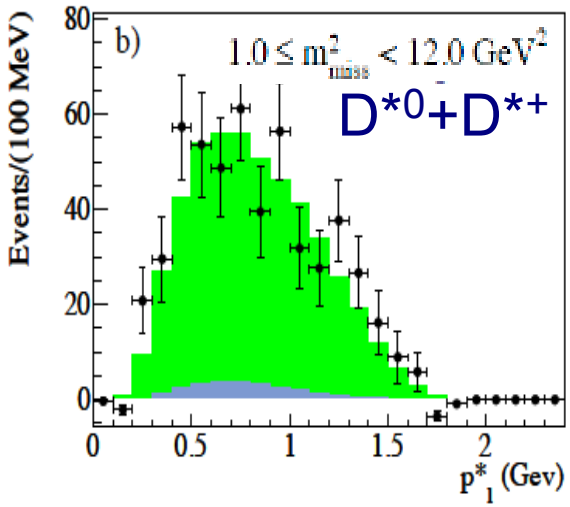
Isospin Constrained

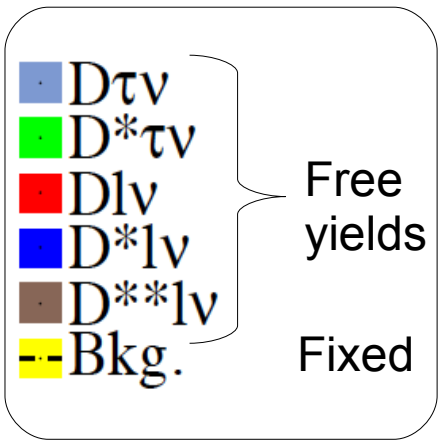
	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^*\tau\nu$
N_{sig}	639 ± 62	245 ± 27	888 ± 63
Significance (σ)	11.3	11.6	16.4
$R(D^*)$	0.322 ± 0.032	0.355 ± 0.039	0.332 ± 0.024

Statistical errors only







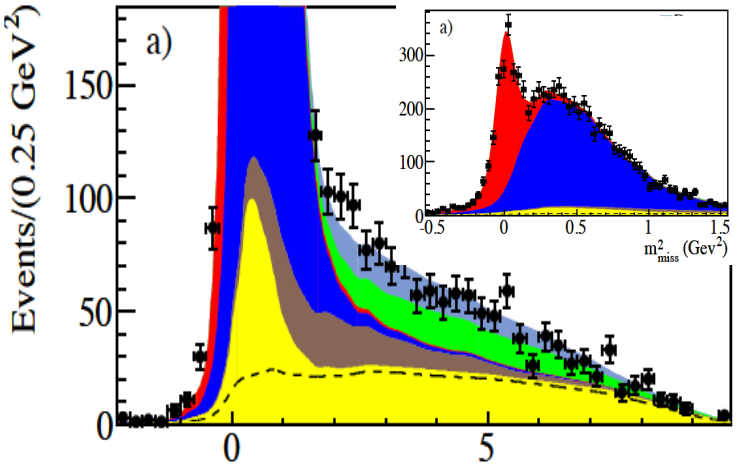


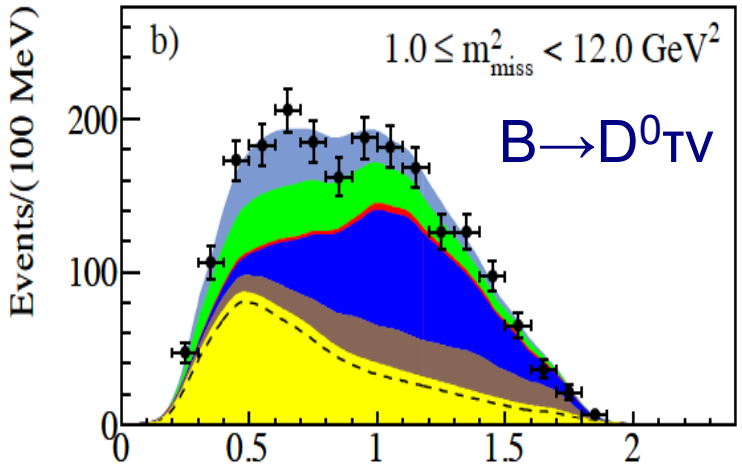
Results of Fit B→Dτν

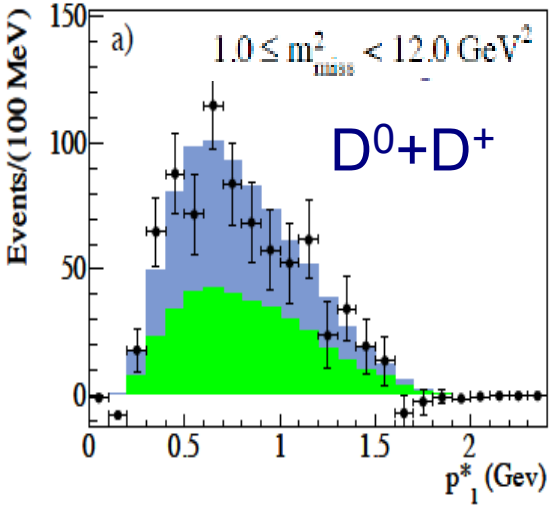
Isospin Constrained

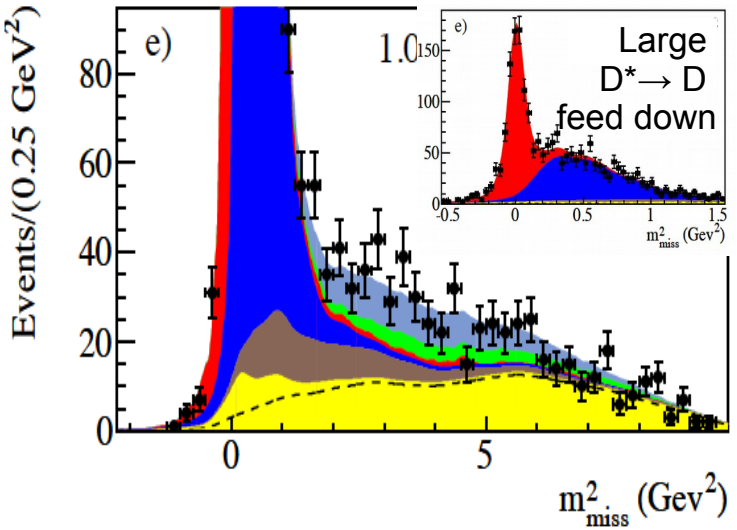
	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

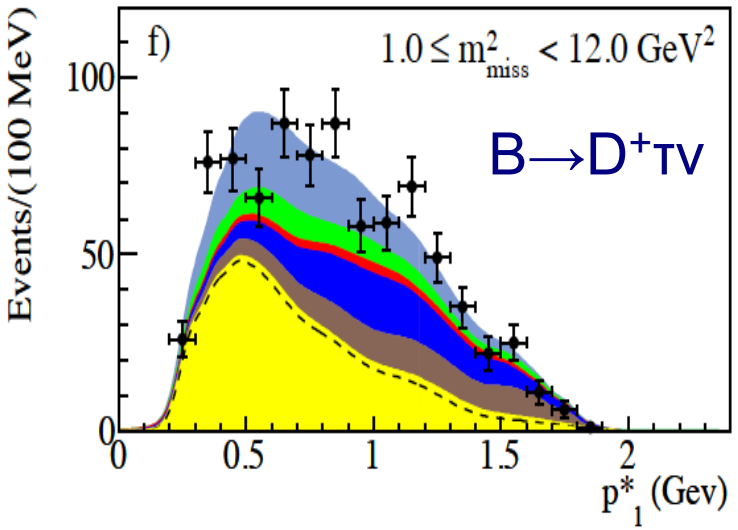
Statistical errors only

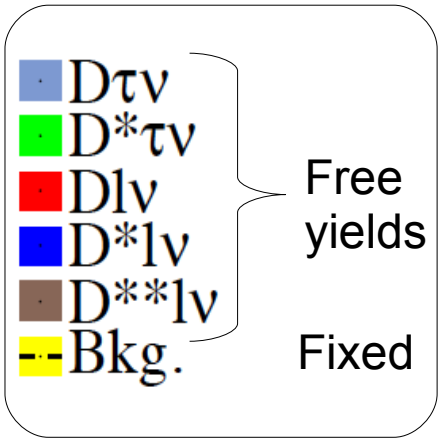






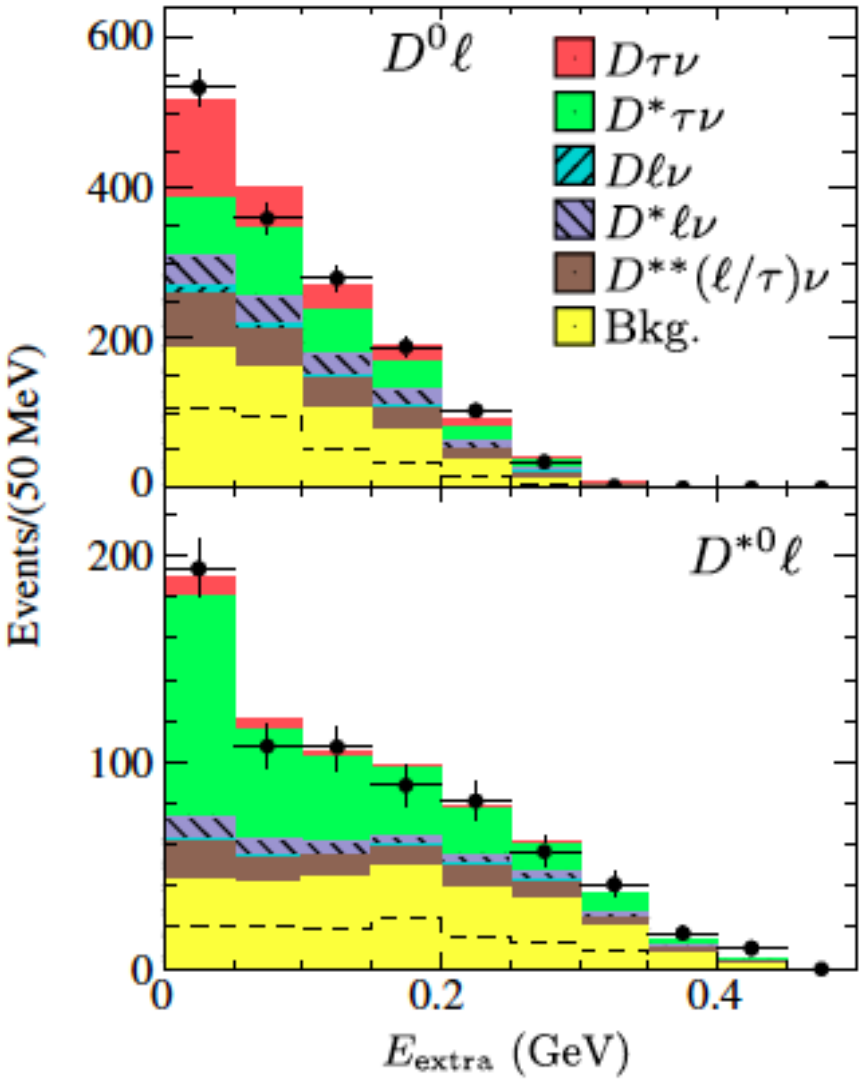


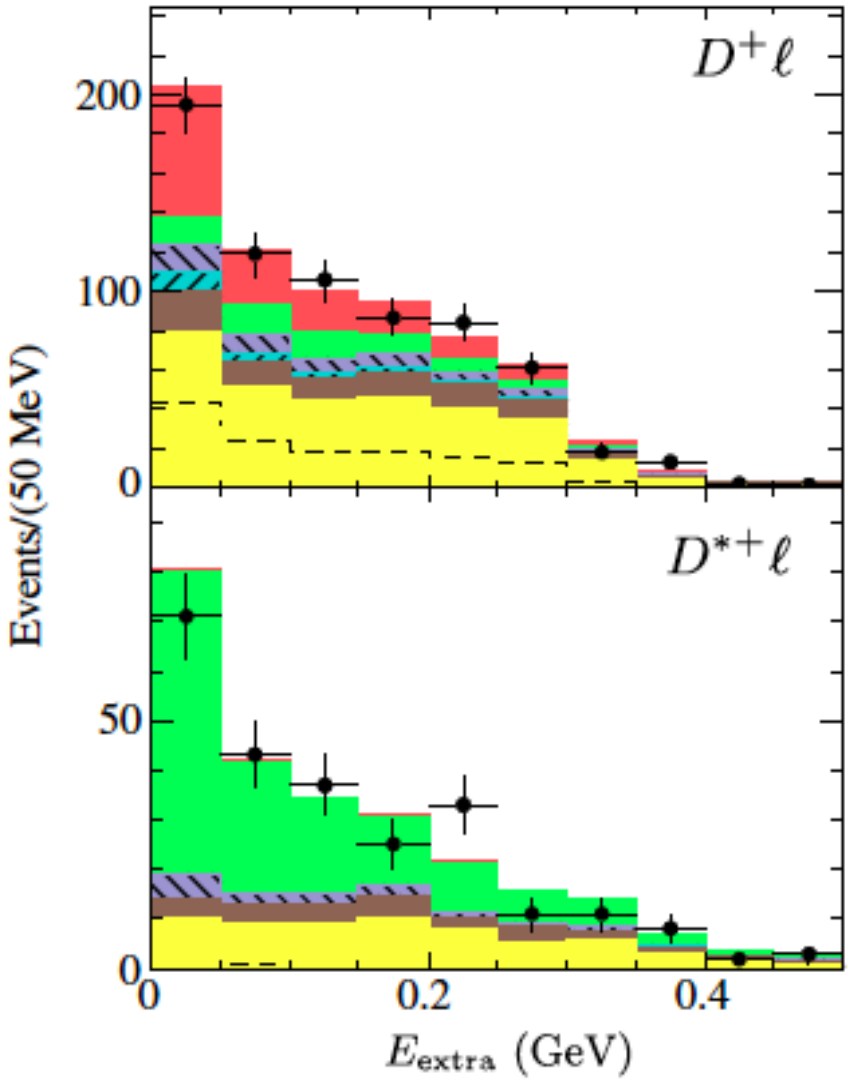




Signal Peak in E_{extra}

- E_{extra} not used in the fit
- Rescaled to the results of the fit: $M_{miss}^2 > 1.5$ GeV^2 (signal enhanced)

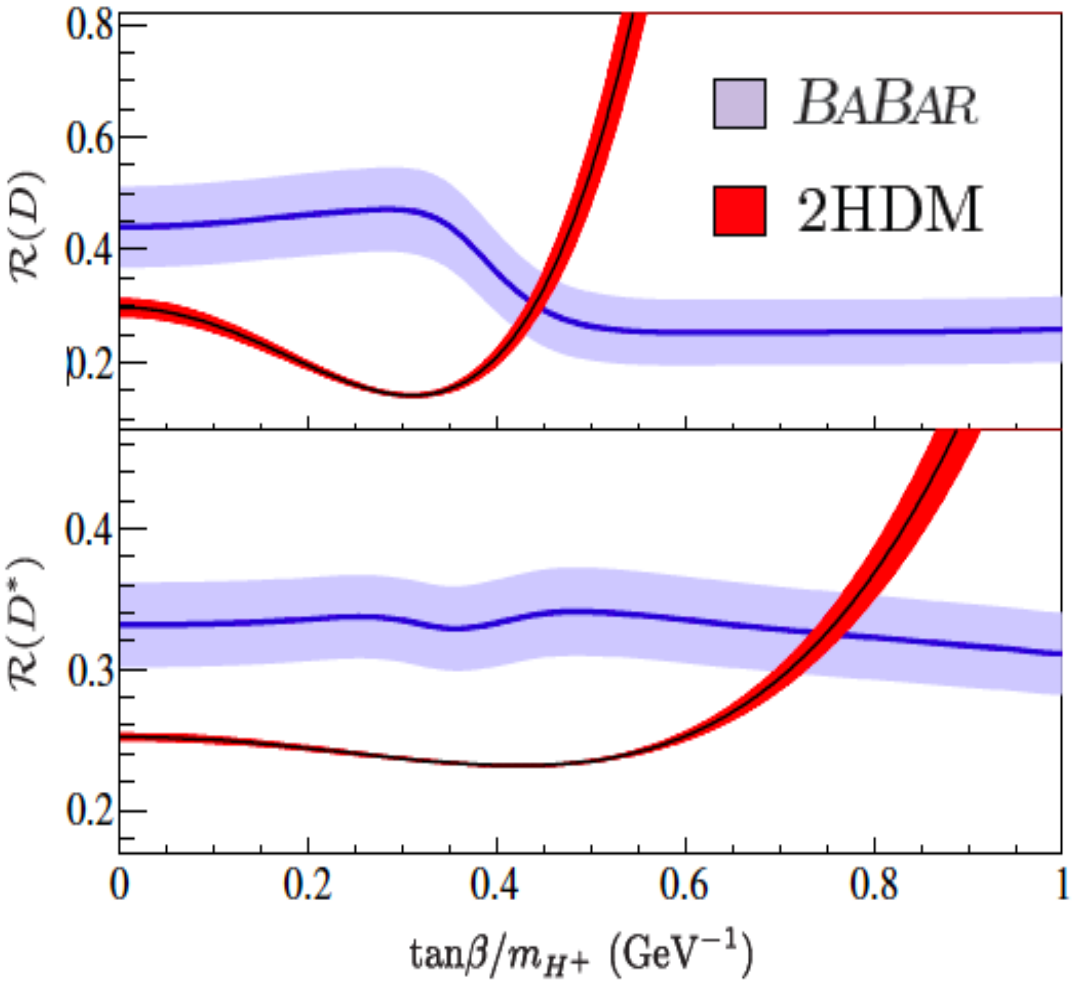




Can we explain the excess events?

- We estimate the effect of 2HDM accounting for the difference in efficiency and its uncertainty
- The data match Type II 2HDM at

$$\mathcal{R}(D) \Longrightarrow \tan\beta/m_H = 0.44 \pm 0.02$$
$$\mathcal{R}(D^*) \Longrightarrow \tan\beta/m_H = 0.75 \pm 0.04$$



- The combination of R(D) and R(D*) excludes the Type II 2HDM in the full tanβ-m_H parameter space (with m_H>10 GeV) with a probability >99.8%
- More general 2HDM can explain the data

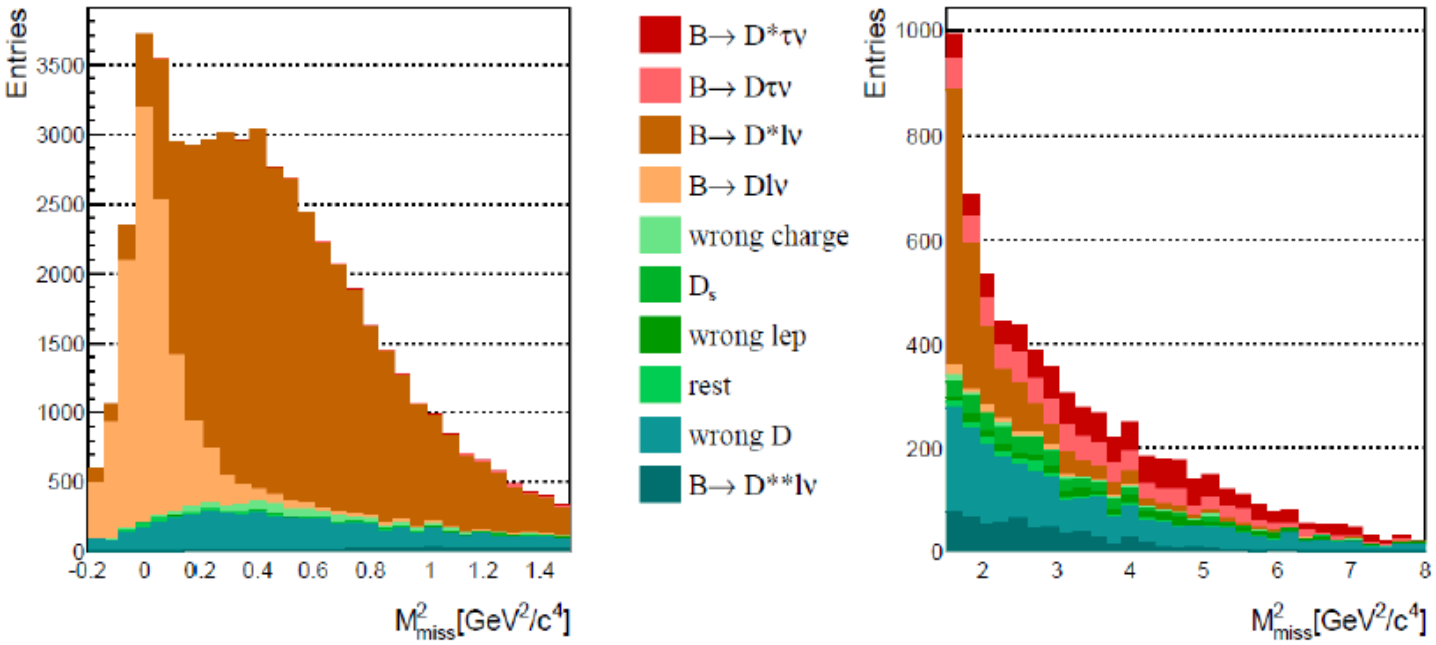
- Low m_H range (m_H<~350 GeV) already excluded by $B \to X_s\gamma$ data!

Signal reconstruction

arXiv:1507.03233

- Four signal samples $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, $D^{*+}\ell$
- No overlap between B_{tag} and B_{sig}
- Zero charge of B_{tag} + B_{sig}
- No further tracks and π^0 in barrel/forward/backward ECL region

$$M_{miss}^2 = (p_{e+e-} - p_{Btag} - p_{D(*)} - p_\ell)^2$$
$$q^2 = (- p_{Btag} - p_{D(*)})^2$$



Fit Strategy

M_{miss}^2 in low M_{miss}^2 sample constraints normalization and cross-feed.

Train a NN to distinguish tau signal and (mainly) D** background in high M_{miss}^2 sample.

Fit the NN distribution in high M_{miss}^2 to get the signal

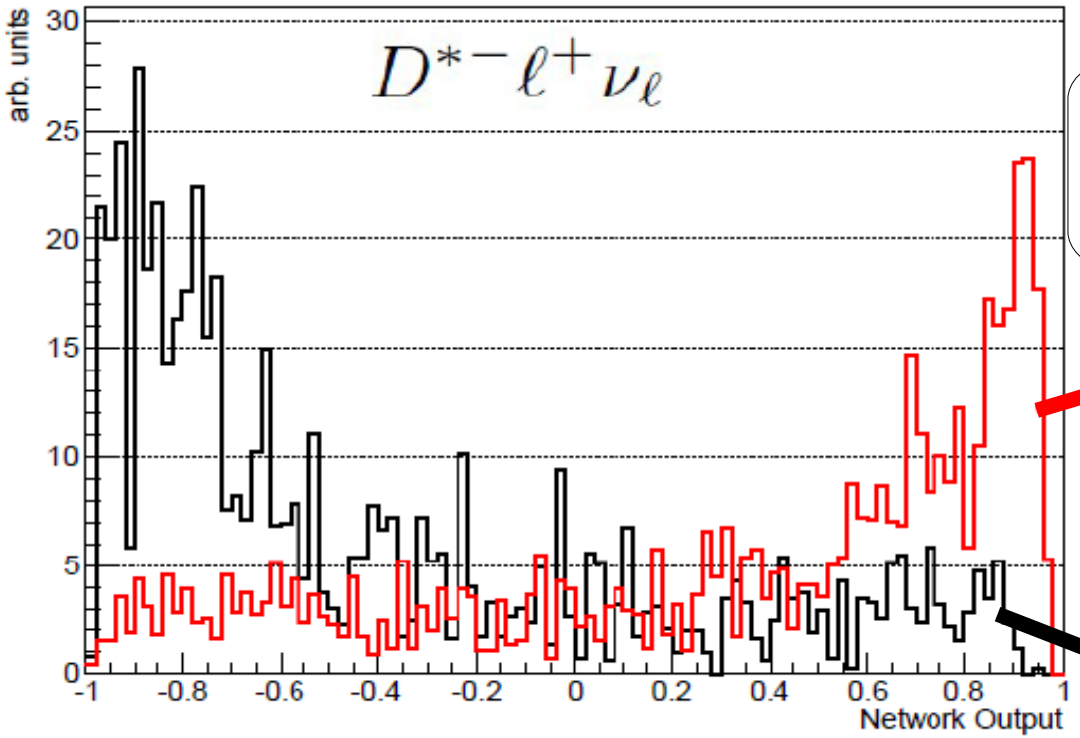
Neural Network

- One N per reconstruction sample
  - Signal: tau signal
  - Background: D**, wrong charge CF, mis-ID lepton, D_s, rest

Input variables:

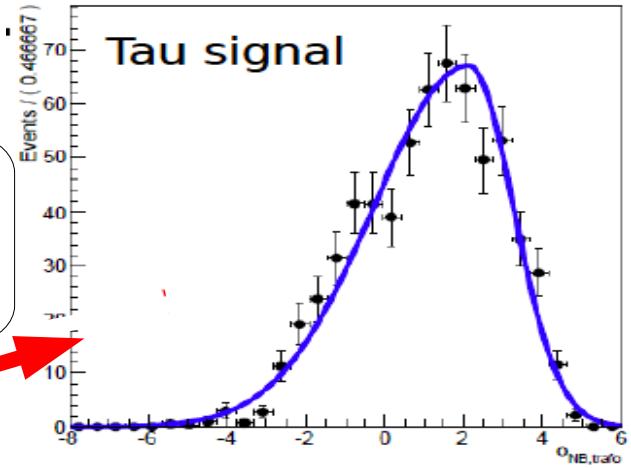
T.Kuhr FPC2015

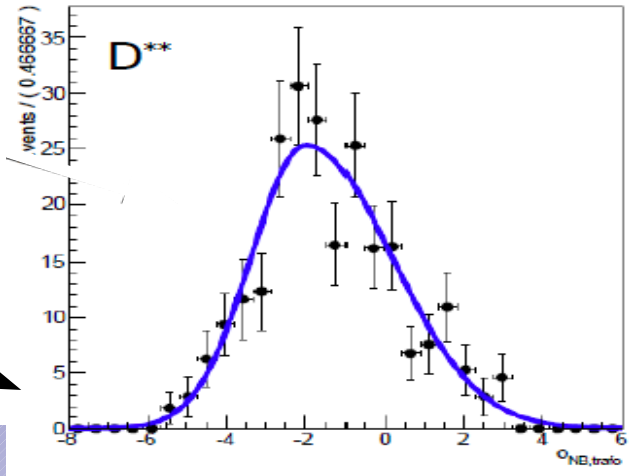
- M^2_{miss}
- E_{ECL}: sum of energies of clusters not assigned to B_{sig} or B_{tag}
  → Most powerful variable
- Momentum transfer q^2 and lepton momentum p^*_ℓ
  → Correlated with M^2_{miss}
- Number of unassigned π^0 with $|S_{\gamma\gamma}| < 5$
- Cos of angle between $D^{(*)}$ momentum and vertex direction
- Decay channel identifiers



NN parametrized

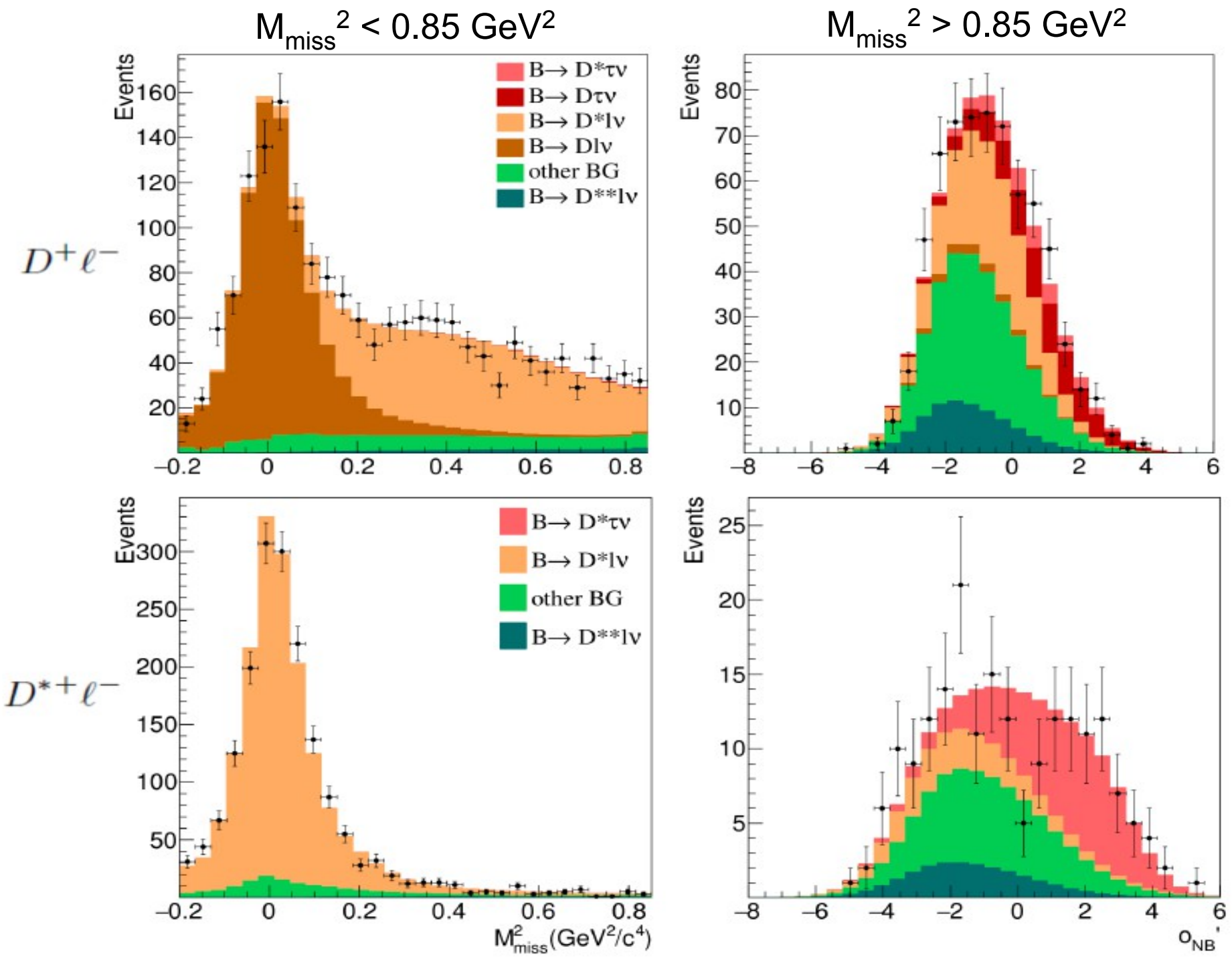
$$o_{NB,trafo} \equiv \log \frac{o_{NB} - o_{min}}{o_{max} - o_{NB}}$$





Fit results

arXiv:1507.03233



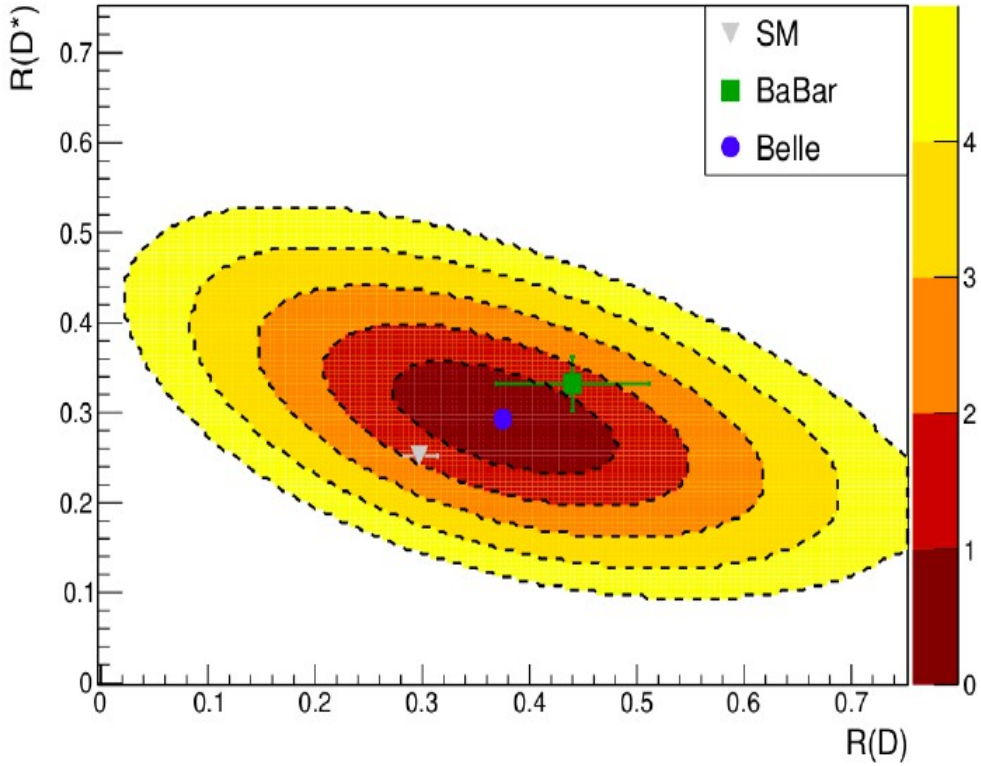
Results

arXiv:1507.03233

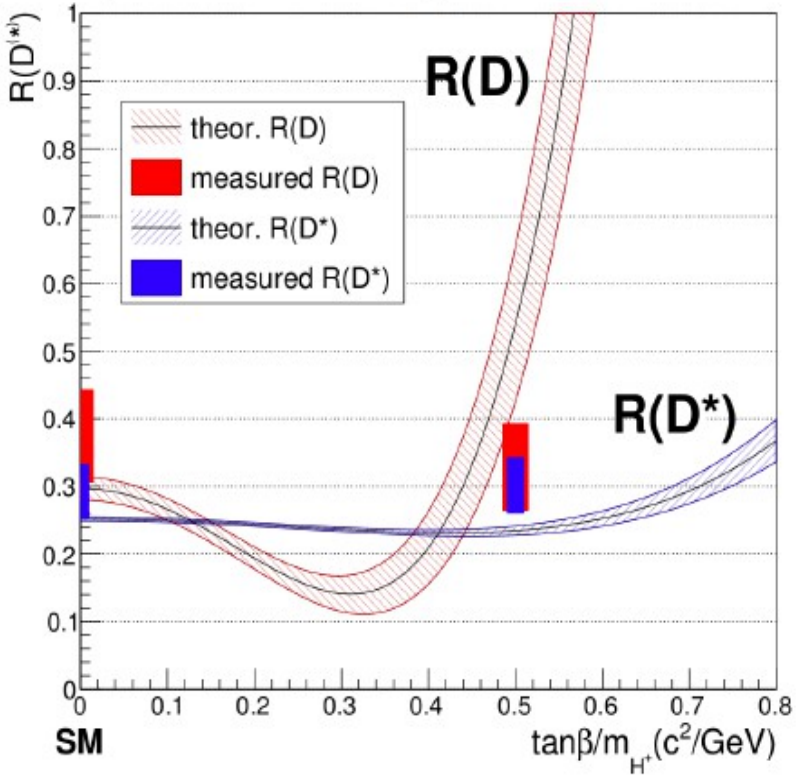
	R(D)	R(D*)
Belle	0.375 ± 0.064 ± 0.026	0.293 ± 0.038 ± 0.038
SM [*]	0.300 ± 0.08	0.252 ± 0.003
∞	1.4σ	1.8σ

Consistent with BaBar and SM

Comparison with SM calculation and BaBar measurement



Fit is repeated with pdf generated from 2HDM type II MC with $\tan\beta/m_{H^+} = 0.5\,c^2/\mathrm{GeV}$



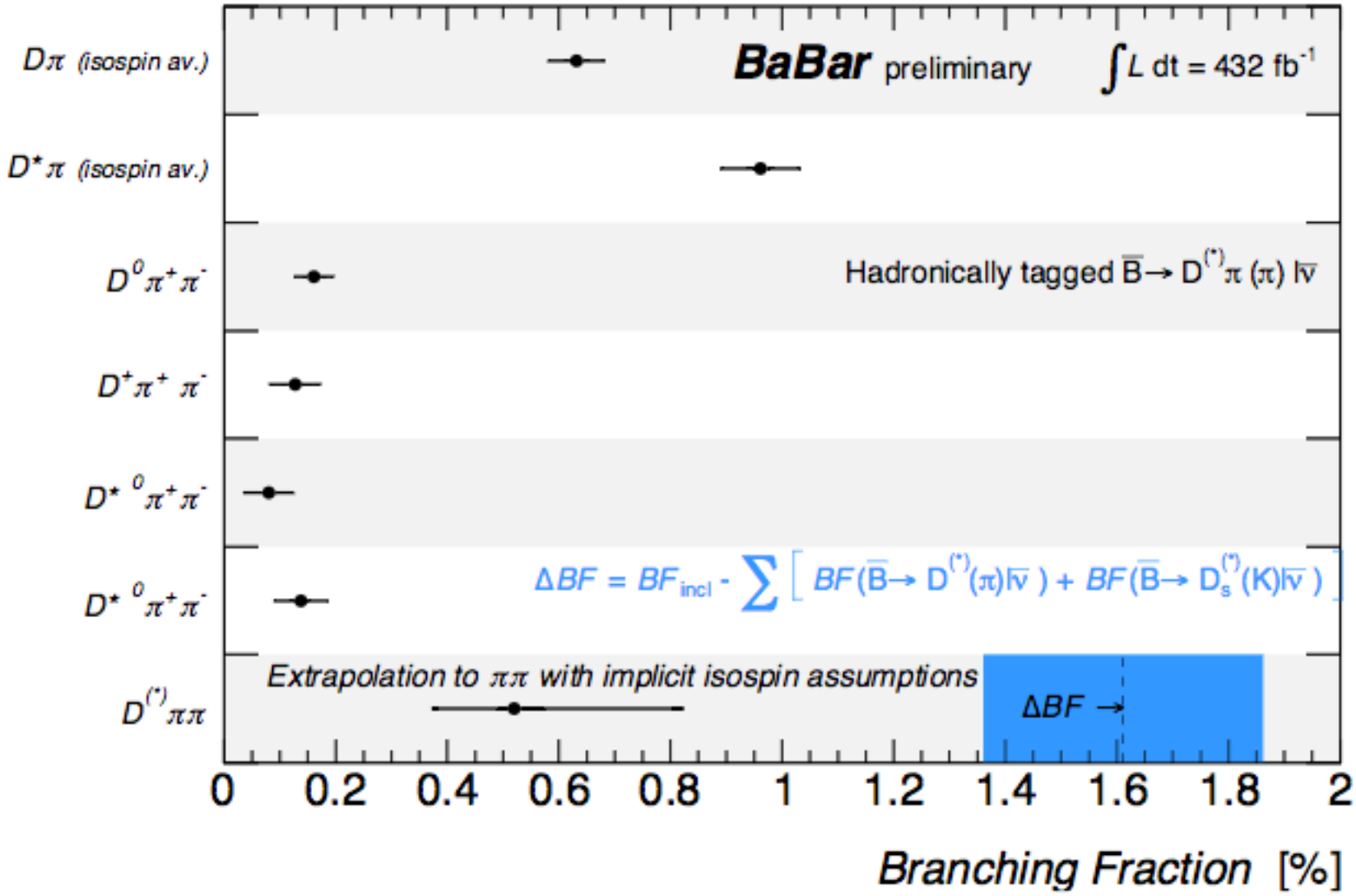
The gap problem

charm state X_c	$\mathcal{B}(B \to X_c \ell \bar{\nu})$ [%]
D	2.29 ± 0.09
D^*	5.43 ± 0.17
$\sum D^{(*)}$	7.71 ± 0.19
$D_0^* \to D\pi$	0.41 ± 0.08
$D_1^* \to D^*\pi$	0.45 ± 0.09
$D_1 \to D^*\pi$	0.43 ± 0.03
$D_2^* \to D^{(*)}\pi$	0.41 ± 0.03
$\sum D^{**} \to D^{(*)}\pi$	1.70 ± 0.12
$D_s^{(*)-} K^+$	0.06 ± 0.01
$D\pi$	0.66 ± 0.08
$D^*\pi$	0.87 ± 0.10
$\sum D^{(*)}\pi$	1.53 ± 0.13
$\sum D^{(*)} + \sum D^{**} \to D^{(*)}\pi + D_s^{(*)-} K^+$	9.47 ± 0.22
$\sum D^{(*)} + \sum D^{(*)}\pi + D_s^{(*)-} K^+$	9.30 ± 0.23
inclusive X_c	10.98 ± 0.14

Inclusive – Σexclusive = (1.51 ± 0.26) %

From T.Lueck @EPS2015

Status of the “gap”



- gap reduced from $\approx 7\sigma$ to $\approx 3\sigma$

extrapolation to full $\mathcal{B}$ assumed $\Gamma(D^{(*)}\pi^+\pi^-\ell\nu)/\Gamma(D^{(*)}\pi\pi\ell\nu) = 0.50 \pm 0.17$

From T.Lueck @EPS2015